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GENERAL ELECTRIC
Review

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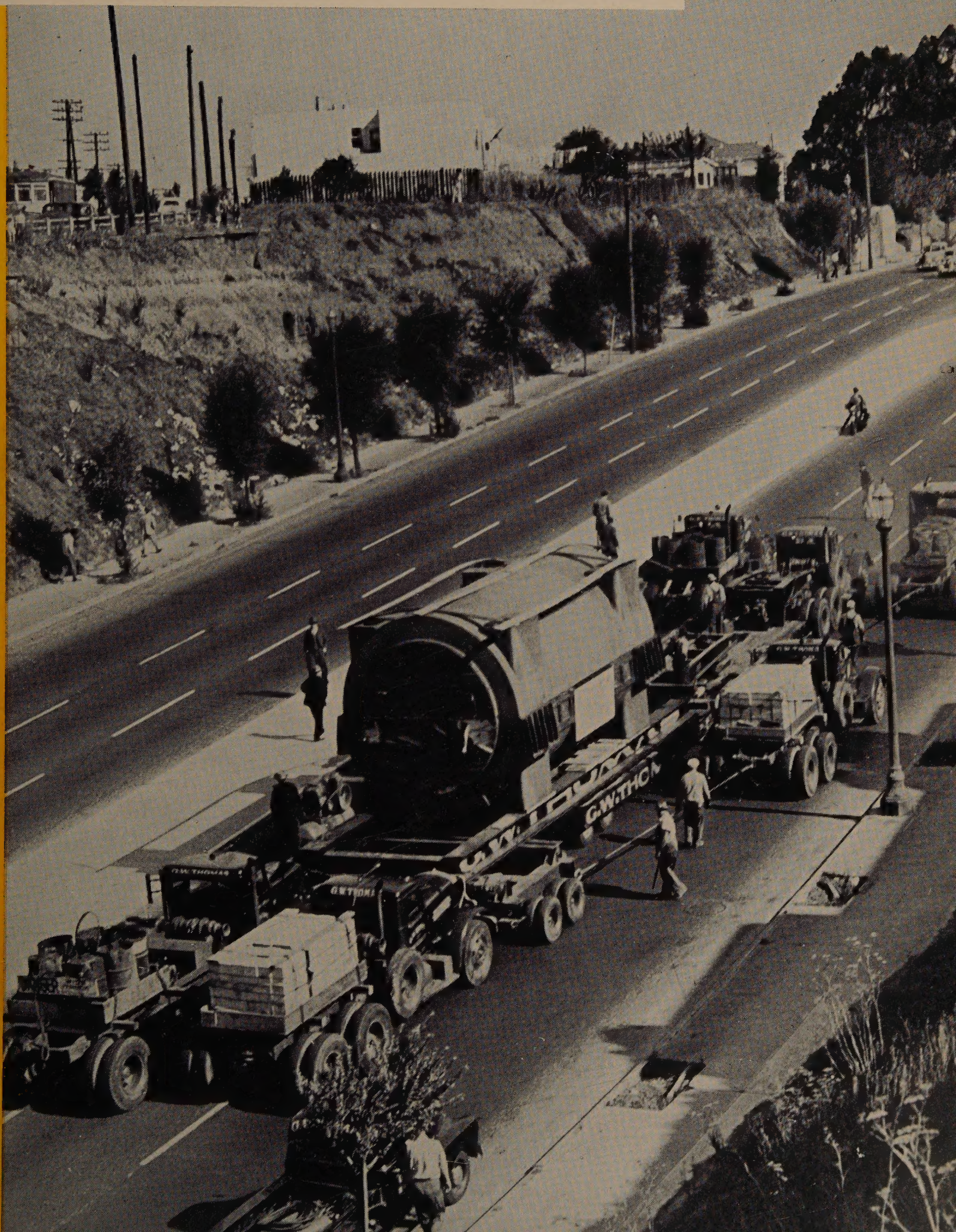

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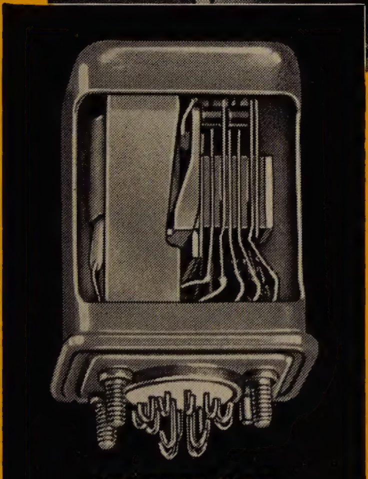
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Write for 36-page Clare Bulletin No. 114

CLARE RELAYS...

First in the Industrial Field

GENERAL ELECTRIC Review

FEBRUARY, 1951
Vol. 54, No. 2

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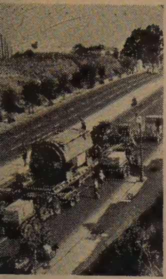
Manager

E. C. SANDERS
Executive Editor

J. E. GLICK
Associate Editor



THE COVER

nerator stator of one of two 111,765-kva m turbine generator units for Station P of ific Gas and Electric Company at San Fran- ear the end of its journey from Schenectady. eing unloaded from a special freight car to trailer it was pulled and pushed by some rucks used to deliver it over the highway destination. This stator weighs nearly 180 nd was assembled and tested at the factory te with laminated core and coils, and shipped piece. (*See page 34*).

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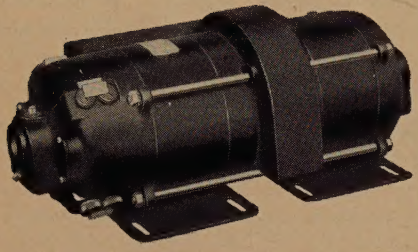
AMPLIDYNES—500 to 25,000 WATTS



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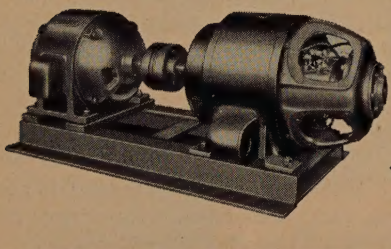

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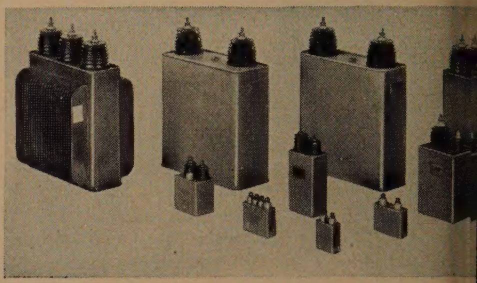

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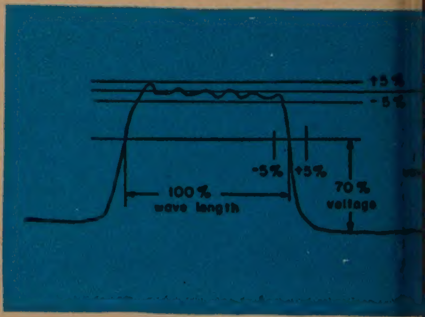
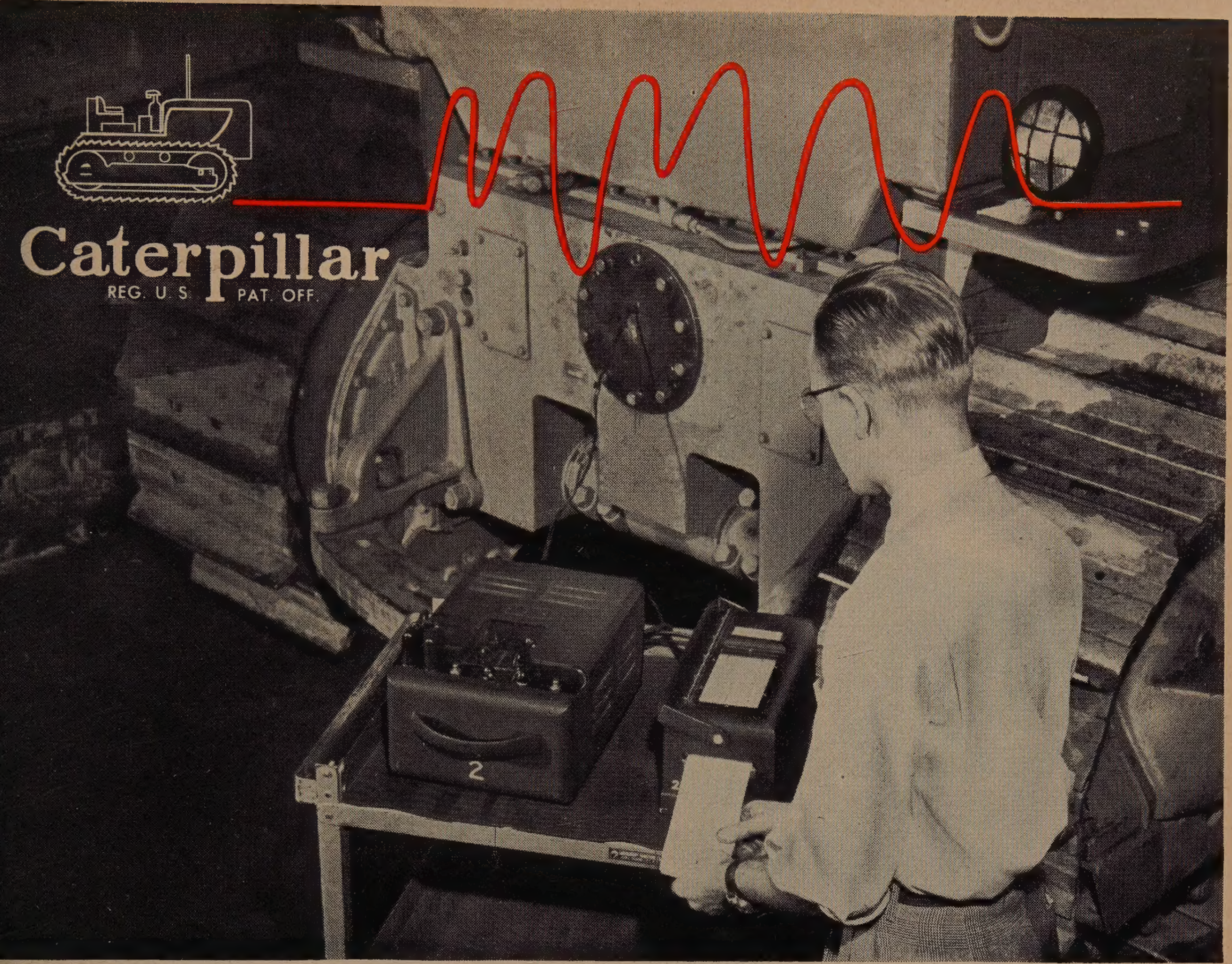


Typical design and operational limits of G E
pulse-forming network: Ripple at top of pulse
Wave length ±5% measured at 70% amp
Capacitance tolerance ±10%

GENERAL ELECTRIC



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GENERAL ELECTRIC Review
VOL. 54
NO. 2
FEBRUARY
1951

EDWARD C. SANDERS

Historian of an Industry

N THIS YEAR of destiny, 1951, the
GENERAL ELECTRIC REVIEW begins its
th year of service to the electrical industry.
the past almost half century, it has seen
d recorded those events of significance
ıich mark the transition between the
sic discoveries of the founders of the in-
ıstry and this generation's complete re-
nce on electric power. Its span of years
nost exactly coincides with the great
lectrical revolution'' which has so tre-
ndously influenced human life.

Many men—in their era—have had the
rception to note transition; relatively few
ve had the initiative or the opportunity
analyze and record its meaning. So far
the electrical industry is concerned, E. C.
nders, Executive Editor of the REVIEW,
s not only been in an excellent position
note its struggles and triumphs but he
s likewise been able to document them.
ıus, it is a simple matter to gage his con-
bution to electrical progress—he has been
e of its great historians.

Edward C. Sanders is a native of Ames-
ry, Massachusetts, where he received most
his early schooling. In 1909, he graduated
m Case Institute of Technology with a
S. in electrical engineering. Upon comple-
n of the G-E Test Course, he joined the
VIEW staff in 1912 as assistant editor. In
22, he was named associate editor, the post
held until 1928, when he was appointed
his present position as executive editor.

The preponderant portion of his business
has been spent in association with engineers and scientists—many of them the outstanding men in their fields. And, peculiarly enough, he seems to have little difficulty either in understanding their traditional whimsies or in editing—to everyone's satisfaction—their treatises. Undoubtedly, this happy circumstance stems from the fact that, like so many technically minded people, he himself is by nature an introvert. This one might not immediately suspect, so well is it concealed beneath a genial demeanor.

Moreover, he has the priceless gift of enthusiasm that can become excited along with any old or budding author over a new technical development. But then his Yankee conservatism asserts itself, and he moves with tact—and caution. A perfectionist by instinct and training, he nevertheless has the indispensable faculty of getting today's work done today.

And, then, there is his ability to bring about that which is desirable—in a way that it would logically occur—while he apparently stands by impartially.

His many years of editorial service could not fail to leave an indelible stamp upon this magazine and its personnel. Therefore, as he retires from his active professional life this month, it seems quite fitting to honor him briefly here—in the pages of the magazine he loved and did so much to build—and served so selflessly. So be it.

H. A. WINNE, Chairman
Editorial Advisory Board

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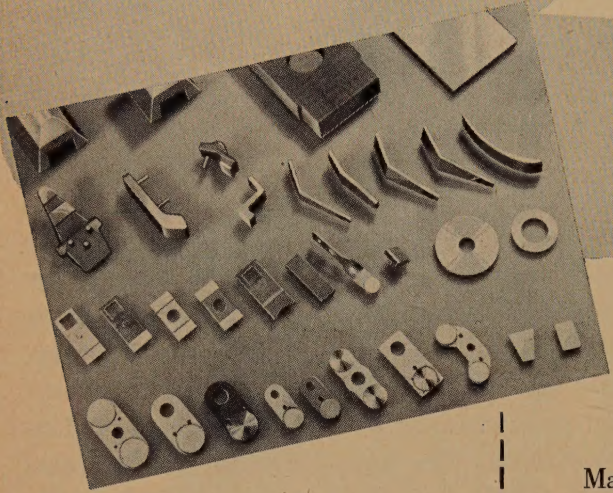

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EMISTRY AND
THE ELECTRICAL ENGINEER

jineering demands and chemical ingenuity unite to produce w and better electrical insulations which increase the reli- lity and extend the usefulness of electrical apparatus

By F. M. CLARK
Division Engineer, Insulation Division
General Engineering and Consulting Laboratory
General Electric Company

N'S advance throughout the ages has been losely coupled to his ability to utilize power urces outside himself. Engineering may well be of its contributions to the progress which has ade in the more efficient generation and utiliza- this power. One source after another has been red, applied, and replaced, each succeeding application being accompanied by another step l in the slow progress of civilization. Animal, nd water power have each contributed its share. the advent of electricity, the engineer seemed reached the pinacle of success in power genera- id utilization. Electricity could be generated tly and in the desired quantity at locations by him and transported with relative ease to ce of its utilization. Such generation, transpor- and utilization, however, introduced problems w type. Among these was the problem of electri- ulation, the problem of supplying materials of retaining the electric power within the tor in which it was generated and transported.

solution of the electrical insulation problem has ntinuously sought by the engineer. Naturally ng materials have been extensively used. But oducts have not been able to meet the increasing al demands presented by the ever-expanding al industry. In consequence, engineering has more and more to chemistry to produce in y the peculiar type of product capable of meet- severe dielectric, physical, and chemical require- of electrical application.

istry had earlier contributed to engineering s in power technology; but, with the growth of power, chemistry was presented with the nity of full partnership with engineering in a ort to assure continued technical progress. This nity was not immediately recognized. Chemis- busily engaged in other fields. A quarter cen- s to pass before the engineer and the chemist comprehend fully their joint responsibilities t opportunities.

g the latter part of the nineteenth century, the ion, transmission, and utilization of electric as almost entirely an engineering responsibility and was attacked in a truly engineering manner by the application of naturally occurring and easily obtainable materials as the "retaining wall" for electric power. Chemical science contributed but little to the infant prodigy in those early days. Air was one of the widely used engineering insulations.

The history of electric power is a story of repeated demands for higher and higher blocks of power generation and transmission. Increasing power loads lead to increasing voltages of transmission for technical and economic reasons. Insulating air was soon replaced by silk or cotton wire coverings, sometimes coated or impregnated with varnish or waxes. Later, natural rubber jackets were applied. Perhaps the first real contribution of chemistry to the science of electrical insulation was the application of vulcanized rubber as insulation for the conductor. But with continued demands for the transfer of larger and larger blocks of power, the inadequacy of available insulation soon became apparent. To provide the engineer with means for adequately meeting the growing demands for electric power has been the opportunity for chemistry. It has met this opportunity and responsibility with a myriad of new products and processes, and with the modification and improvement of older materials and processes.

THE CHEMIST'S PROBLEM

Electrical insulation is the pipe line by which electric power is carried from the point of its generation to the place of its ultimate conversion into useful work. Electrical insulation may also be regarded as the cornerstone upon which the whole electrical industry has been built. Metals are conducting. Air is nonconducting. Hence it was on air that the engineer largely depended for insulating the conducting members of his early machines. But air has only a limited ability to withstand voltage stress; and with increasing demand for higher voltages of power transmission, the engineer soon found that to use air as an insulant resulted in bulky insulation spacings for the conducting members of his machines. Faced with the necessity for compactness, the engineer turned to mineral oil. The use of oil permitted the design of apparatus with marked economy of space as compared to the use of air.

With continued increasing voltage demands, however, the engineer soon realized that his insulating

---

icle is so paged that, without mutilating other articles, it can be oved for filing as a group of full-size consecutive pages.—Editor problem was a problem of materials. The physicist has been an important contributor to the proper understanding of dielectric behavior. But progress in insulation demands more than a proper understanding of the fundamental behavior of dielectrics in the electrical field. To know why a material does or does not work is important but it is not an end in itself. To have such information points only to the demand that materials be synthesized to meet more efficiently the severe requirements of engineering service in accordance with the physical dictates discovered. And it is here that the chemist finds his problems and his opportunity. The synthesis of insulations capable of meeting the extremes of voltage and temperature to which they may be subjected in practice and to provide a suitable means for their proper maintenance in operation are indeed the problems of chemical science.

QUALITY CONTROL

Modern industry has clearly recognized the advantage of a close control of quality in all of its materials and processes. Perhaps in no other industry, however, has the engineer sought more assiduously for an acceptable chemical control of quality than in the insulations used in electrical manufacturing. Chemical purity has a peculiar and distinctive meaning when applied to electrical insulation. The recognized dependence on insulation for the successful operation of electrical equipment, and also the requirements imposed by the demand for superior and stable dielectric and mechanical properties—not only in the material as applied by the manufacturing engineer but also during years of commercial service under widely varying conditions of use—have been responsible for the exacting quality specifications which have become identified with the insulating materials of the electrical industry.

Typical of the demand for superior quality has been the search for an acceptable test to assure freedom from sludge formation in mineral transformer oil. The transformer in its normal operation generates heat, and one of the problems of the transformer designer is the proper dissipation of that heat. Mineral oil serves the dual purpose of increasing the dielectric strength of the assembly, as compared to the use of air or other gases, and of providing a means for adequate heat dissipation from the core and coils of the transformer. In large part, this heat is transferred to the cooling surfaces of the transformer by circulation of the oil.

It is not a difficult engineering problem to make certain that the proper heat-dissipating properties are built into the design of the transformer. Mineral oil, however, when oxidized undergoes physical and chemical changes which, unless checked, ultimately vitiate the most careful engineering design calculations. Severe oxidation results in an increase in the viscosity of the oil and thus reduces the rate of oil circulation. Exhaustive oxidation results in oil-insoluble products which accumulate in the ducts provided for proper oil circulation and which settle on and coat the inner tank walls and cooling surfaces. The combined effect may be obstruction of heat transfer and dissipation t extent that the transformer is no longer prop cooled. Chemical research has, therefore, been dire for many years toward the establishment of a suit test which will evaluate the oxidation and slud propensity of new mineral transformer oil and w will supply the operating engineer with informa needed for the proper evaluation of the oxidation sludging hazard that is presented by the continued of an oil after years of transformer operation.

The chemist has supplied the engineer with a var of methods for evaluating the oxidation and slud properties of mineral transformer oil. On the in national level, the various methods suggested are b correlated by the International Electrotechnical C mission under the leadership of Dr. Henri Wies France. In the United States, the engineer look the American Society for Testing Materials for g ance and advice in this and other problems of chem control and dielectric testing.

In the problem of oil oxidation, the Amer Society for Testing Materials has evolved two dist methods of test(1) for evaluating the sludge-form properties of the oil. These include a short-time h pressure oxidation test for acceptance control purp to assure maintenance of quality standards from shipment to shipment. A second type of test involv longer-time oxidation of the oil and is set up prima for research and development purposes. In an enti different type of test, the ASTM has set up(2) an studying the possible application of the tension w exists at the interface between mineral oil and w as a criterion of the degree of oil oxidation and sl ing (FIG. 1). The successful engineering applicatio chemical developments of this type will solve impor engineering, manufacturing, and operating problem

SYNTHETIC INSULATIONS

Important as may be the contributions of chemi in the modification and improvement of natu products such as mineral oil and cellulose sheets, important as may be the development of chem methods for the quality control of the older dielect on which the present successful manufacture of e trical equipment has been built, the value of chemi to engineering is intimately related to its ability synthesize products for specific engineering applica in order to meet the more stringent requirement the future. And in this respect, chemistry, in its p nership with engineering, is contributing its share insure uninterrupted progress in the field of electr insulation.

The military and industrial exigencies of World II presented an accelerated engineering demand insulating materials capable of successful applica under extreme conditions of operation. The dem extended the limits of operation to temperature least as low as −55 C and as high as 150 C or hig Chemistry has met this demanding situation. It ed synthetic gases to replace air and nitrogen :heir use has been threatened by the more severe ric requirements. It has produced new types of tic liquids, solids, and insulating varnishes and each with its own improved characteristic and apable of use in its own field for the mitigation

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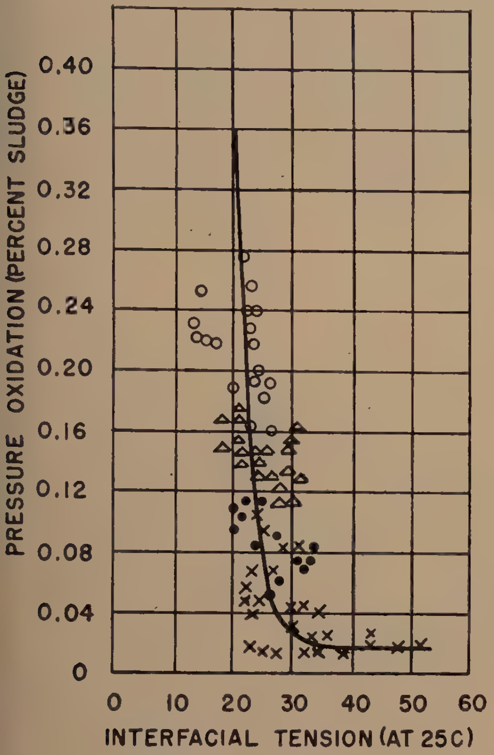
(1)Numbered references are listed at the end of the article.



Correlation of the pressure oxidation (sludge) and interfacial values which have been observed in mineral oil during transfomer on(2)

× Good quality oil
● Medium quality oil
○ Poor quality oil
△ Reclaimed oil

ssible elimination of the defects and engineering ions which have heretofore been intimately ted with the operation of electrical equipment.

JS INSULATION

engineer and the physicist have shown that the ric strength of air is approximately in linear n to the distance separating the oppositely l conductors. This factor coupled with air's ely low dielectric strength necessitated bulky ement of conductors in machines designed to he growing demands of industrial application. ering study of the other easily available gases no practical advantage or improvement. And ie problem rested for many years.

in their voltage limitations, air, nitrogen, and gases susceptible of practical application are nt dielectrics. The technical limitations, however, fixed and immutable. It has only been as the f physical and chemical studies that these limitations have been rolled back beyond all expectations. hysicist discovered the dielectric advantages t in the use of the so-called electronegative

Many of the electronegative gases are not applicable for engineering use either because of their chemical reactivity and corrosive properties or because of the physical limitations imposed by their inherent behavior at the low or high temperatures of use. Sulfur hexafluoride, however, possessed the required chemical stability and inertness. Over a wide range of temperature, sulfur hexafluoride maintains the required consistency in physical state. But sulfur hexafluoride was not available in practical quantities for engineering exploitation. Its quantity production has been the chemists' contribution to the progress of engineering in the development of improved gas-filled electrical equipment.(3)(4)

The properties of sulfur hexafluoride are listed in Table I. Fig. 2 illustrates the 60-cycle dielectric strength of sulfur hexafluoride and other electronegative gases as compared to the dielectric strength of nitrogen. The 60-cycle voltage strength of a gas is

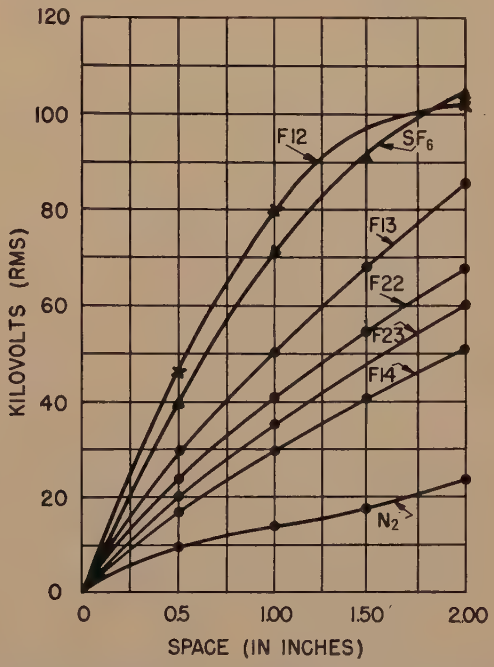


Fig. 2. Sixty-cycle dielectric strength of gases tested between tungsten rod and one-inch diameter sphere at atmospheric pressure(4)

F12: Dichlor—difluor—methane
F13: Monochlor—trifluor—methane
F14: Tetrafluor—methane
F22: Monochlor—difluor—methane
F23: Trifluor—methane
SF$_6$: Sulfur hexafluoride

TABLE I

PROPERTIES OF SULPHUR HEXAFLUORIDE GAS

Colorless, odorless, tasteless	
Relative density	5.03 (Air=1)
Specific gravity (liquid)	1.91
Weight	0.406 lb/cu ft
Melting point	−50 C
Boiling point	−63.8 C (Sublimes)
Critical temperature	54 C
Coefficient of expansion	0.027
Dielectric constant at 27.5 C	1.00191
Specific heat at −2 C	0.14271 cal/gr
Heat conductivity	7.1×10^{-5} cal cm^{-1} deg^{-1}

not, however, the only dielectric criterion of value in engineering application. Electrical apparatus is frequently subjected to surge voltages. The most serious of this type of voltage application owes its source to

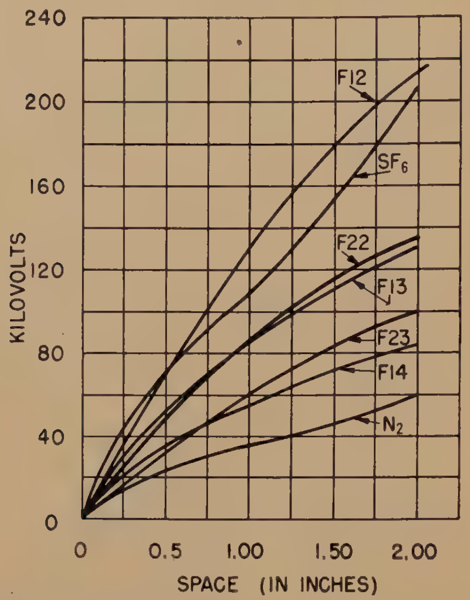


Fig. 3. Negative-impulse tests (1½ ×40 microsecond wave), at atmospheric pressure, of several gases tested between tungsten rod and one-inch diameter sphere(13)

F12:	Dichlor—difl or—methan
F13:	Monochlor—trifluor—methane
F14:	Tetrafluor—methane
F22:	Monochlor—difluor—methane
F23:	Trifluor—methane
SF$_6$:	Sulfur hexafluoride
N$_2$:	Nitrogen

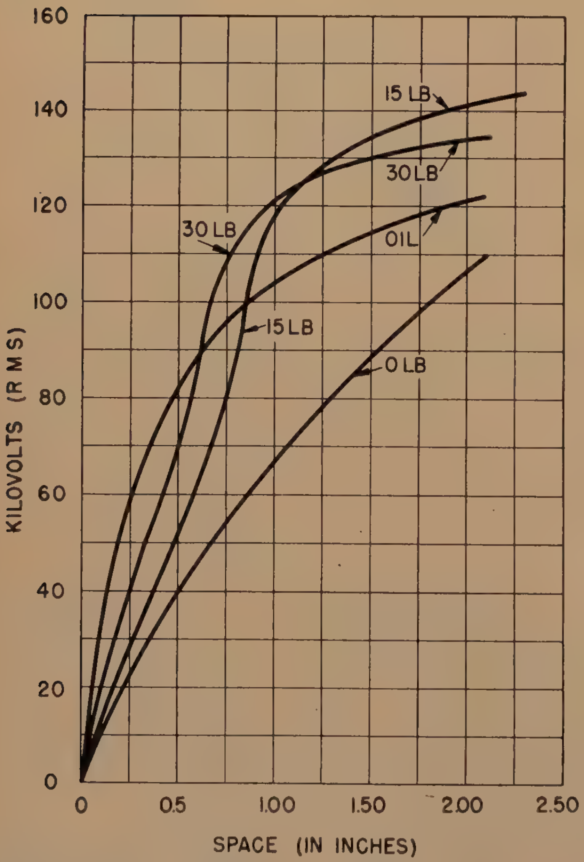


Fig. 4. Sixty-cycle dielectric strength of sulfur hexafluoride gas(4). Tests made between tungsten rod and one-inch diameter sphere (grounded). Dielectric strength of oil shown for comparison.

lightning. Since the duration of the voltage surg
extremely short, voltages of this type are freque
referred to as impulse voltages. Because of their
impulse-voltage strength, compared to that of min
oil, air and nitrogen have been limited in many of t
applications. Fig. 3 illustrates the dielectric impr
ment exhibited by sulfur hexafluoride as compare
nitrogen when tested under impulse voltages. With
application of increased gas pressure, the 60-c
dielectric strength of sulfur hexafluoride is substant
equal to that associated with mineral oil (Fig. 4).

LIQUID INSULATIONS

To the operators of high-voltage electric appara
insulating liquids are commonplace. To many opera
of such equipment, the designation "insulating liq
means mineral oil. Mineral oil has had a long
enviable record as one of the major insulations in h
voltage technique. It is used in transformers (Fig
as the dielectric and cooling medium, and used as
impregnant for the paper insulation of lead-cov
cable (Fig. 6). In circuit breakers, mineral oil is
quently the major arc-interrupting medium. In cap
tors (Fig. 7) mineral oil was formerly widely used
success as the impregnant of the paper dielectric.
use in capacitors, however, has now been lar
replaced by askarel, a product of synthetic chemis
But the use of mineral oil has not been without
attendant difficulties. Most of these difficulties
chemical in nature and are susceptible to attack
solution by chemistry.

The petroleum chemist has worked wonders
improving the dielectric and chemical properties
mineral insulating oils. He has studied the meth

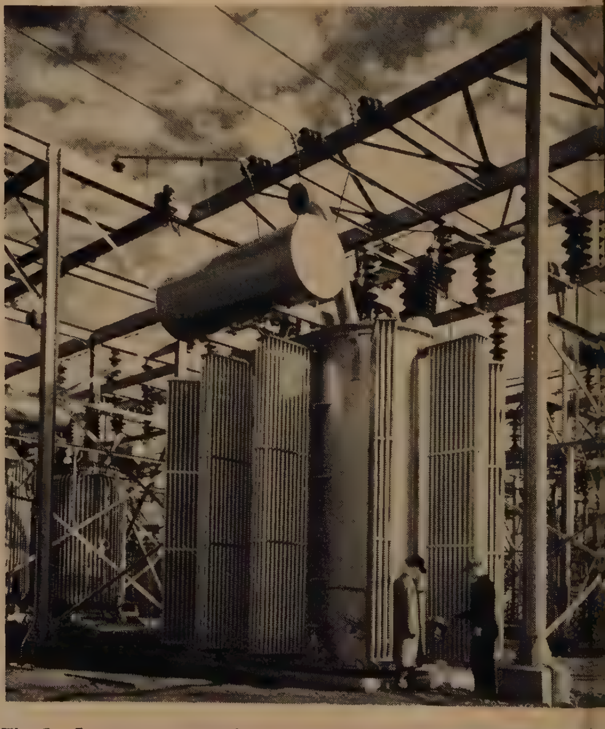
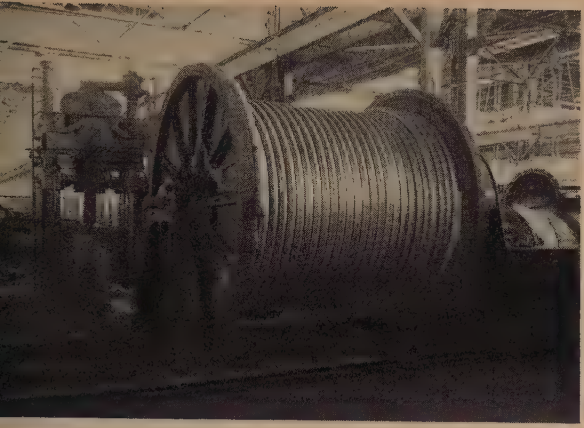
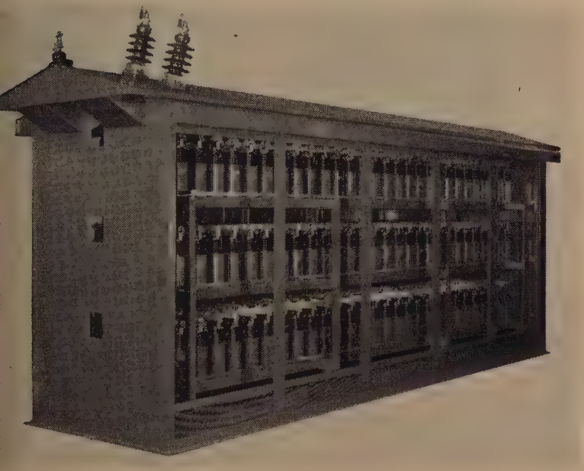


Fig. 5. Large power transformers equipped with oil conservators, as
engineering solution to the cooling-and-dielectric oil oxidation problem



6. Three-conductor cable of the type having mineral-oil-impreg- l paper as insulation. The cable is here shown being reeled from the sheath press



7. Large rack-type unit of capacitors. Mineral oil has been used ex- vely as the liquid impregnant in capacitors but has now been largely rseded in this application by the synthetic product askarel

the degree of refinement best suited to produce al oils for special dielectric applications. One oil ansformer use has been produced with a maximum ance to oxidation and sludge formation. Another so treated as to produce the greatest dielectric ity under the conditions of high-voltage-stress cations which are encountered in the use of capac- and lead-covered cables. But despite all efforts to ice the most stable product, mineral oil will still ze.

e engineering solution to the oxidation problem protect the oil by the use of inert-gas atmospheres echanical devices such as the oil conservator is illustrated on the transformers shown in FIG. 5. e chemical solution of the oxidation problem is to nt oxygen's attack by the use of oxidation inhibi- One of the most promising of such inhibitors is ry dibutyl para cresol, which has been demon- d in the laboratory to inhibit strongly the forma- of sludge in an oil subjected to oxidation. G. H. Fuchs(5) has presented data comparing the sludg- haracteristics of inhibited and noninhibited trans- r oils in distribution transformers during a special un with top-oil temperatures of 90 C (FIG. 8). recently, transformer designers and operating engineers have been greatly intrigued by the possibilities envisaged in this type of chemical solution to what has long been a difficult engineering problem.

ASKAREL

Mineral oil oxidizes. Mineral oil burns. When decomposed by the electric arc, mineral oil evolves flammable gases which in admixture with air present the possibility of fire and explosion. These possibilities of operating trouble have been reduced or eliminated by the chemical development and engineering application of the synthetic dielectric liquids known as askarels, of which Pyranol(6) dielectric is one. Askarels are defined(7) as "synthetic, nonflammable type insulating liquids which, when decomposed by the electric arc, evolve only nonexplosive gaseous mixtures." Askarels have been applied in two principal fields of engineering use. They have found important application in capacitor and transformer manufacture.

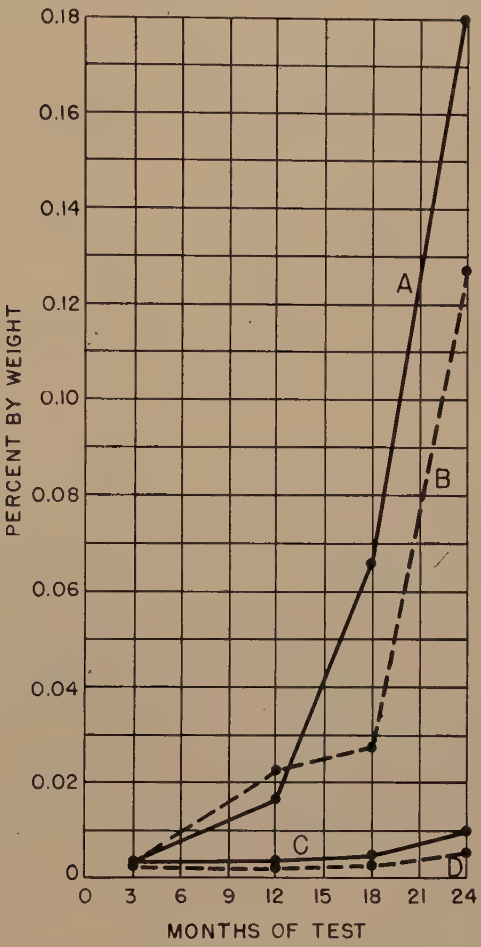


Fig. 8. Sludge formation in mineral-oil-filled transformers as affected by presence of an oxidation inhibitor. Based on reference(5)

A: Conventional transformer oil (10 kva); old
B: Conventional transformer oil (15 kva); new
C: Inhibited transformer oil (10 kva); old
D: Inhibited transformer oil (15 kva); new

Pentachlordiphenyl has been synthesized by the chemist for capacitor use. It is manufactured by the chlorination of diphenyl which, in turn, is obtained by the controlled pyrolysis of benzene. On chlorination, the dielectric constant of the hydrocarbon diphenyl is substantially increased.(8) The pentachlordiphenyl contains 54 percent chlorine and possesses a suitably low power factor (Fig. 9) to permit its application as an impregnant for paper-spaced capacitors (Fig. 10). The high dielectric constant of the pentachlordiphenyl as compared to mineral oil (2.2) has presented the engineer with a material which, when applied as an impregnant for paper-spaced capacitors, has resulted in a marked reduction in the physical size of the capacitor per microfarad of electric capacitance (Fig. 11).(9) Since the designer of capacitors is continuously confronted with the demand for capacitors of smaller and smaller physical size, the development of pentachlordiphenyl has been a chemical contribution of important engineering value.

Pentachlordiphenyl, however, is not suited for application as a cooling and dielectric liquid in transformers. Its characteristics are given in Table II. It will be noted that, as compared to a normal transformer oil, pentachlordiphenyl possesses a high viscosity and a pour point which is but little below normal room temperature. But by proper blending of pentachlordiphenyl and trichlorbenzene (another typical askarel) marked lowering in the viscosity and pour-po characteristics are obtained (Figs. 12 and 13). A bl of this type suitable for transformer use is descri in Table III. The blend described is composed chlorinated diphenyl containing 60 percent chlorine weight and trichlorbenzene.

But still the contribution of the chemist to engine ing progress had not been completed. An electric ar askarel produces hydrogen chloride, the corros nature of which, under the conditions of normal tra former use, is clearly recognized. Despite the excelle of the engineering design and performance of askarel-filled transformer, the possibility of an elect arc in the askarel compelled the practical eliminat of this corrosion possibility. This has been acco plished. The chemist has developed the use of tetraphenyl, which dissolved in askarel effectiv prevents the insulation and metallic corrosion wh has been heretofore associated with arc decomposit of askarel.(10) Fig. 14 illustrates the advantages companying the use of the tin tetraphenyl as a prot tive agent against corrosion by the gases evolved fr the askarel when decomposed by an electric arc.

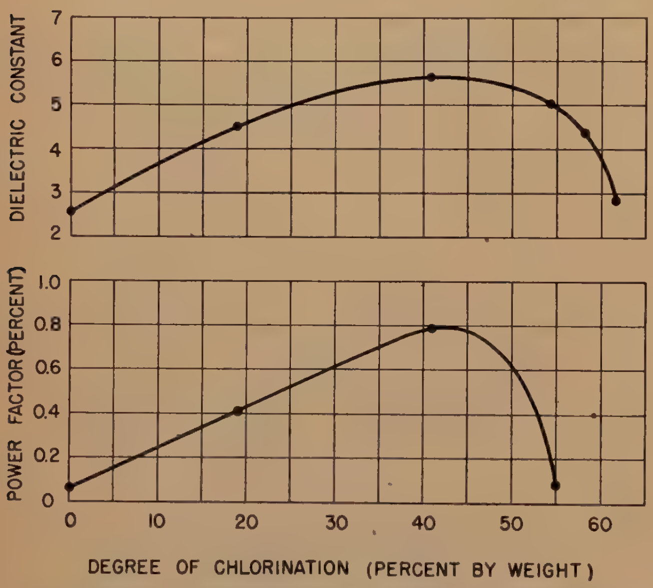


Fig. 9. Change in dielectric constant and power factor of the hydrocarbon diphenyl as affected by degree of its chlorination.(8) Tests made at 1000 cycles

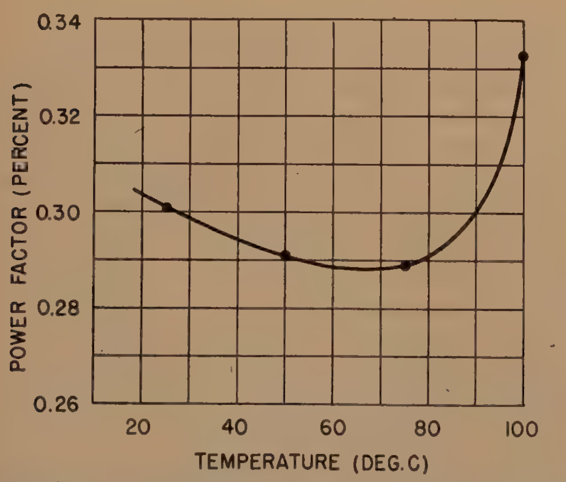


Fig. 10. Power factor—temperature relation in kraft paper capacitors impregnated with pentachlordiphenyl(10)

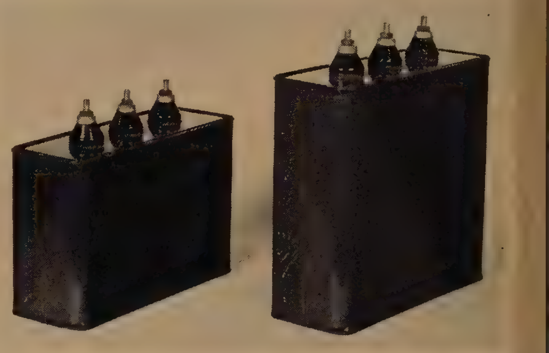


Fig. 11. The use of pentachlordiphenyl instead of mineral oil mak possible considerable space and weight saving in capacitors, as indicat by this comparison of two units of the same rating

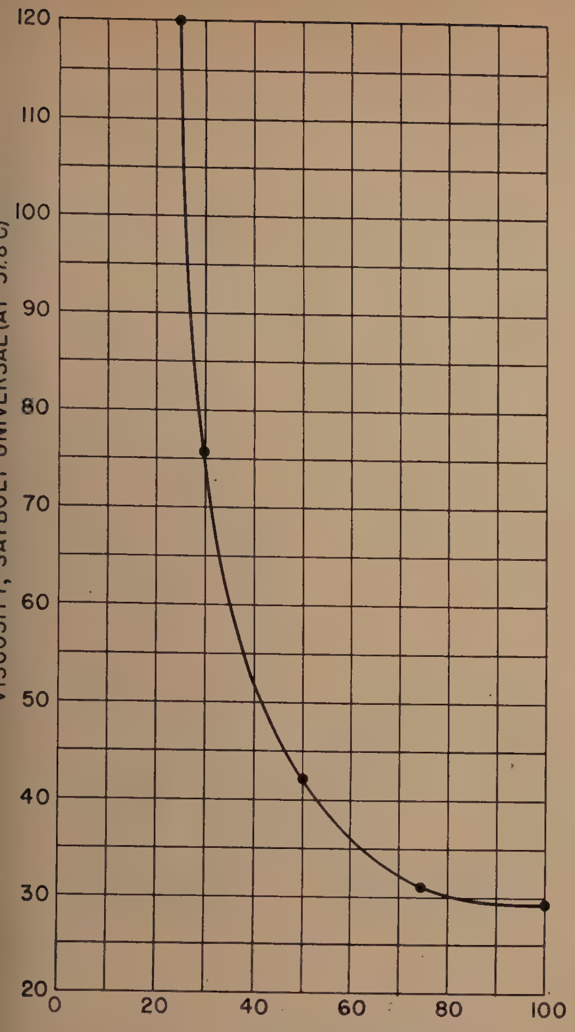
LIQUIDS FOR HIGHER-FREQUENCY USE

Mica has been the insulation most widely used wh voltages of the higher frequencies were to be encou tered. Its low dielectric loss and high dielectric consta have combined to favor its use in capacitors. T

TABLE II

COMPARATIVE PROPERTIES OF PENTACHLORDIPHENYL AN MINERAL TRANSFORMER OIL

	Pentachlor-Diphenyl	Mineral Transformer Oil
Color	Light yellow	Light yellow
Viscosity (Saybolt)		
at 98.9 C	45 seconds	34 seconds
at 37.8 C	2000 seconds	55 seconds
Fire point	Does not burn	145 C
Dielectric constant at 25 C	5.0	2.2
Dielectric strength at 25 C	35 kv	30.0 kv
Pour point	+10 C	−40 C



12. The extent to which the viscosity of pentachlordiphenyl is ed by the addition of trichlorobenzene(10)

ncies of World War II, however, limited the ability of mica for many industrial applications ompelled the development of a suitable substitute ower-capacitor use where the frequency of the ge applied was substantially higher than the al 60-cycle power frequency. Such an application n the manufacture of capacitors for use in elec- heaters. The use of high-frequency currents and ges industrially is largely for heating where speed

TABLE III

PARATIVE PROPERTIES OF TRANSFORMER GRADE PYRANOL DIELECTRIC AND MINERAL TRANSFORMER OIL

	Transformer Pyranol Dielectric	Mineral Transformer Oil
	Light yellow	Light yellow
ity (Saybolt) at 37.8 C	55 seconds	55 seconds
oint	−35 C	−40 C
oint	Does not burn	145 C
tric constant at specific ity of 15.5 C/15.5 C	1.565	0.880
tric constant at 25 C	4.8	2.2
ric strength at 25 C	35 kv	30 kv
ion characteristics	None	Sludges

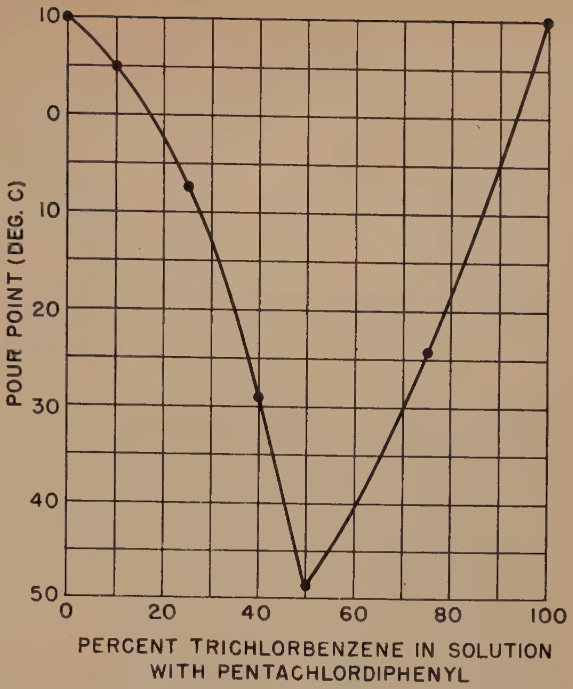


Fig. 13. How the pour-point temperature of pentachlordiphenyl is changed by the addition of trichlorobenzene (10)

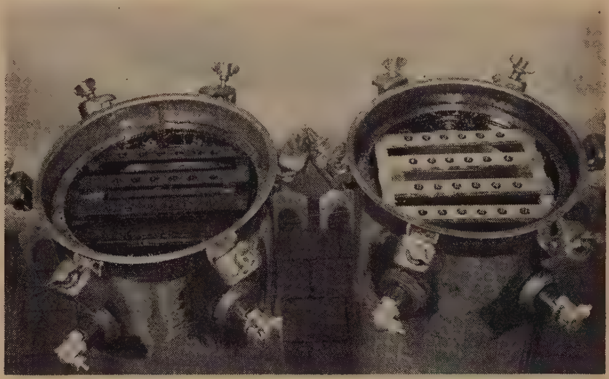


Fig. 14. The use of tin tetraphenyl dissolved in askarel prevents severe corrosion by hydrogen chloride evolved when askarel is subjected to electric arcing, as evidenced by the transformer at the right. The one on the left was not so protected

in attaining a localized temperature for a short interval is fundamentally important. The heating of metals by induction and the heating of nonconducting materials by dielectric absorption have been widely applied.(11) As a substitute for mica in these power-capacitor applications at voltage frequencies up to one megacycle, the chemist has supplied the engineer with an organic ester liquid, dibutyl sebacate.(12) The properties of dibutyl sebacate are described in Table IV.

Dibutyl sebacate has been used by the capacitor engineer as the sole insulation between the oppositely charged armatures of his capacitor. Liquid dielectrics have been traditionally acceptable for high-voltage use only when used in conjunction with a solid insulation. In capacitors, this solid insulation is largely kraft tissue. In the higher-frequency range of application, as in power oscillators, the use of cellulose sheet has not been practical from the standpoint of dielectric loss. The result has been the engineering development of a capacitor which is noteworthy because of the entire

TABLE IV

PROPERTIES OF DIBUTYL SEBACATE
FOR ELECTRICAL USE

Color	Water white
Viscosity (Saybolt) at 37.8 C	46 seconds
Specific gravity at 15.5/15.5 C	0.939
Flash point	170 C
Fire point	210 C
Pour point	−10 C
Dielectric constant at 25 C	4.3
Power factor at 500,000 cycles per second, 25 C	0.0001

absence of cellulose insulation between the electrode plates. The satisfactory operation of the capacitor is entirely dependent on the efficiency of the insulating liquid used. The development and application of dibutyl sebacate represents another successful effort, jointly conceived and jointly executed by the chemist and the engineer.

Dibutyl sebacate has a dielectric constant of about 4.3 as indicated in Table IV. This gives the material a substantial advantage over mineral oil (dielectric constant 2.2) in that it enables the capacitor engineer to design capacitors of small physical size as compared to oil-filled capacitors of similar capacitance. Dibutyl sebacate is also characterized by an advantageously low power factor in the frequency range from 100 to 1000 kc. This, combined with its excellent stability of dielectric strength, has enabled the engineer to produce a capacitor (Fig. 15) which is technically superior to the mica capacitor. What was originally conceived as a substitute in an emergency has, therefore, been converted by the chemist and the engineer into another step forward in engineering progress.

Fig. 15. Dibutyl sebacate offers a number of advantages to other dielectrics for high-frequency capacitors, as in this one for electronic-heater resonant-circuit applications

SOLID INSULATION

In engineering technique, the solid insulation serves as a mechanical separator and as a dielectric barrier between oppositely charged conductors. The dielectric strength of a composite assembly is generally considered as being largely determined by the dielectric strength of the solid barrier. From this point of view, the liquid impregnant generally used in high-voltage applications of solid insulation serves chiefly to displace the air and to prevent the formation of voids and low-press gaseous areas within the solid, the presence of which conducive to destructive ionization and electric charge leading to the ultimate destruction of the electric itself. In lower-voltage practice, as in mot and other rotating equipment, the impregnant is m frequently a resin or other solid which is required meet severe mechanical demands in addition to cert of the usual dielectric requirements.

Cellulose has given the engineer excellent service one of the principal solid insulations since the ea days of the electrical industry. In the form of shee tapes, and pressed boards, cellulose has been continua improved by the chemist to meet the continui demands of its electrical usage. Cellulose insulati sheets and tapes can be produced with a wide range density and porosity consistent with the spec requirements of the electrical application. Prope dried and impregnated, cellulose possesses a suitab low dielectric loss and high dielectric strength at pow frequencies. Where a solid of high dielectric consta is desired, as in electric capacitors, cellulose with value of about 5 has met the requirements. But desp the excellence of its properties, its easy availabili and its fine record in commercial operation, the of cellulose still presents technical limitations in t design and operation of electrical equipment. As wi mineral oil, most of these limitations arise from caus which are chemical in nature and are susceptible attack by chemistry.

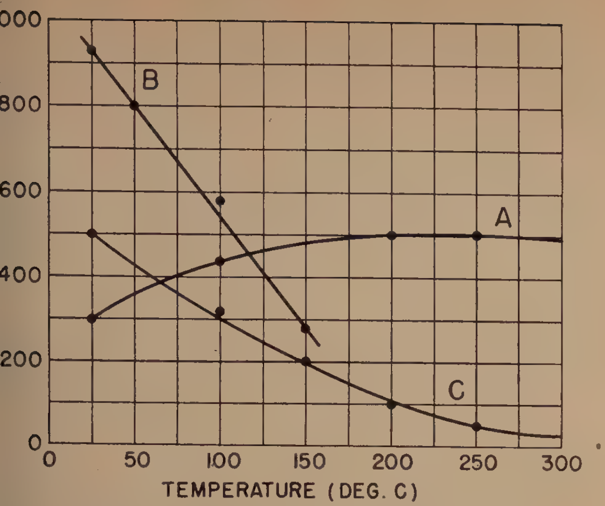
Cellulose insulations are classified by the engineer "Class A" materials. Because their chemical and mecha ical deterioration becomes more pronounced as t temperature is increased, cellulose (Class A) insulatio are restricted in their engineering applications to maximum temperature of 105 C. Among the mo recent products of synthetic chemistry are insulatio which are capable of being operated at substantia higher temperatures.

INSULATIONS FOR HIGH TEMPERATURE

Asbestos in tape and sheet form has long been us as the solid insulation for high-temperature operatio Recent developments have greatly improved its tra tional dielectric properties. Terratex and quinter insulations possess improved electrical properties.(18

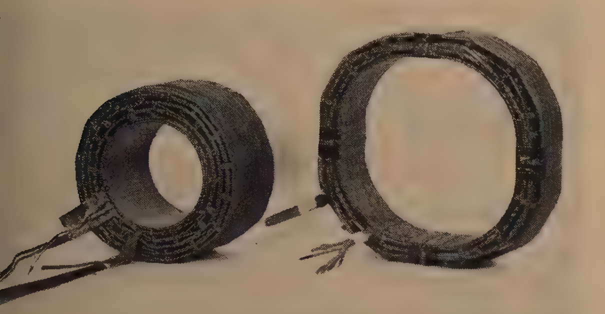
Asbestos fibers are flexible, but asbestos sheets a tapes contain many impurities which limit their u as a dielectric. In terratex, the asbestos fiber has bee prepared in small dimensions and with a freedom fro impurities and conducting particles to a degree n considered as commercially feasible in the usual asbest sheet. ~~These fibers have been~~ combined to give a thi flexible inorganic sheet or tape similar in appearance the usual cellulose paper. In Fig. 16, the dielectr strength of terratex is compared to the dielectr strength of glass and porcelain. Fig. 17 shows an app cation.

Fiber glass is another inorganic material which h been produced in tape and sheet form for use where t



16. **Breakdown strength of untreated terratex and some other in- nic insulations(13)**

Untreated terratex, two 0.006-in. sheets, total thickness 0.020 in.
Pyrex glass, 0.030 in.
Porcelain, 0.055 in.



17. **Terratex insulated coils for 550-amp air-cooled arc-welding sformer(13)**

er operating temperatures are encountered. Such ations as terratex, fiber glass, and the like, how- are most commonly used in combination with a -melting solid or thermosetting resin binder which ws the base material with properties sufficient to the severe mechanical and dielectric requirements eration. Depending on the type of binder used, insulations are classified by the engineer as Class : Class H insulations. Class B insulations are marily limited in operation to a maximum tem- ture of 130 C. Satisfactory operation of Class H ations has been claimed at temperatures as high 0 C and for short periods even as high as 250 C. ch type of insulation has its traditional "main- " In Class A materials it has been cellulose. The tional liquid dielectric has been mineral oil. And g the binders used with asbestos as Class B in- ion, dependence has for years been placed on ac. Despite its many advantages, however, shellac ing displaced in engineering application by many ous products of synthetic chemistry. Phenol- aldehyde resins were among the first of these rials to find commercial use. Debing(14) has given cellent resumé of their dielectric properties. Phe- resins have been used extensively in combination cellulose (Class A) and in combination with tos (Class B) insulations. More recently, however, engineering interest has been attracted to those resin products which are able to be operated at temperatures above that normally accepted as satisfactory for the phenolic-resin binders. Among these products are the silicones and the fluorinated hydrocarbon polymers widely known under the trade name Teflon.

SILICONES

The members of the silicone family of compounds differ radically from the usual hydrocarbon insulations in that their structural composition is based on networks of alternate silicone and oxygen atoms. Organic dielectrics such as the petroleum oils, rubber, and the phenolic resins possess a structural arrangement based upon the bonding of carbon to carbon. The silicone compounds possess, to some degree, an inorganic character as a result of their chemical structure. As described by Rochow,(15) however, the silicones are not ceramic in nature nor do they possess the chemical stability of fused quartz or porcelain. The presence of organic groups (carbon-to-carbon bonding) reacts against this high degree of thermal stability but their presence is necessary in order to provide the resin with flexibility and plastic behavior. Sufficient stability remains, however, to endow the silicones with a thermal reliability far exceeding that which is manifested by the carbon-to-carbon structural arrangement of the usual organic insulants.

Among the silicone compounds of interest to the electrical engineer are the silicone liquids. These are produced with a wide range of viscosity, from an extremely low water-like viscosity to liquids having a viscosity exceeding 1000 centistokes at room temperature. Each is characterized by a temperature coefficient which is much lower than that of petroleum oils of similar viscosity value. The pour point of even the more viscous silicone liquids is as low as −50 C, the thinner liquids having a freezing point as low as about −85 C. Because of their resistance to oxidation and their marked stability at high temperature, these liquids have been applied as damping and hydraulic fluids, as foam inhibitors in petroleum compositions, as mold release agents, and as special high-temperature lubricants.

Their electrical properties have been found superior in many respects to the best of the mineral-oil insulating liquids. The dielectric constant and power-factor

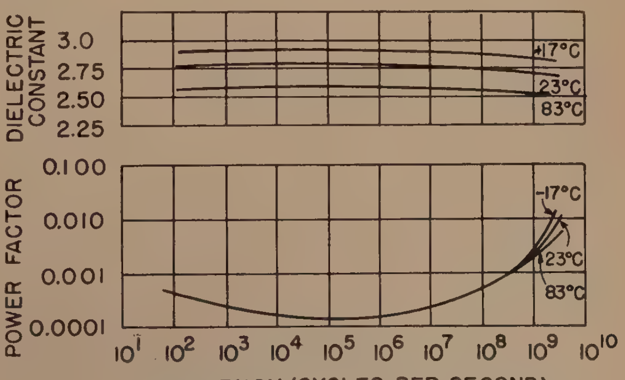


Fig. 18. Dielectric constant and power factor of liquid silicones(16)

characteristics are illustrated in FIG. 18 for a silicone liquid having a viscosity of 12,000 centistokes. The dielectric strength of the liquid silicones is comparable to that of mineral oil and is subject to the same deteriorating influences in practical use. Their freedom from oxidation and sludge formation, however, coupled with their marked stability at high temperature, presents the engineer with another means of eliminating operating difficulties which have long been associated with the dielectric use of mineral oil. Dielectric application of the silicone liquids is at present limited to use where their particular thermal-stability advantages will offset their greater initial cost.

It is the resin members of the silicone family of compounds, however, which have attracted the widest engineering interest and commercial application. The silicone resins possess a wide range of physical properties. Their introduction, usually in combination with glass, mica, or asbestos products, has provided the engineer with a new class of electrical insulation which has been designated as Class H. Class H insulations, although not yet clearly defined in all their various applications, are considered as generally applicable for operation as high as 180 C. Their use provides the engineer with a means of designing units which are smaller in weight and size, and which are subject to higher overload conditions with greater safety, than does the use of conventional insulations. A typical silicone resin which is applicable for bonding mica, mica tape, and glass-mica combinations, or as a coating material for glass cloth or sleeving, is described in Table V. This resin develops good bonding properties for high-temperature use.

TABLE V

PROPERTIES OF GENERAL ELECTRIC SILICONE RESIN NO. 9989-1

Solids content		60±5%
Viscosity at 25 C		150–250 cp
Specific gravity of solution		1.017
Specific gravity of solids		1.017
Weight per gallon		8.45 lb
Drying Time		
Temperature C	*To Tack-free Film*	*To Tough, Hard Film*
150	15 to 30 min	24 hours
200	Less than 15 min	1 to 2 hours
Preferred Baking Schedule		
80 C		3 hours
150 C		3 hours
200 C		3 hours
250 C		4 to 5 hours
Dielectric Strength at 25 C		2000 vpm
Power factor at 60 cycles, 25 C		0.0026
Dielectric constant at 60 cycles, 25 C		2.91

The general characteristics of the silicone compounds and their application as electrical insulating materials have been described by Bass and his co-workers.(16) FIG. 19 compares the high-temperature stability of a typical silicone resin with a phenolic-alkyd resin varnish customarily used in electrical practice. Totally enclosed, fan-cooled induction motors built with hig temperature silicone insulation have been subject to cyclic heat tests for as long as 5400 hr at 280 C wit no marked deterioration of the resin as indicated insulation resistance and high-potential tests. A 75- 450-rpm 440-volt motor has been operated successful at temperatures as high as 300 C. Extrapolated te data based on the 10 C rule of deterioration wou indicate many years of satisfactory service at 200

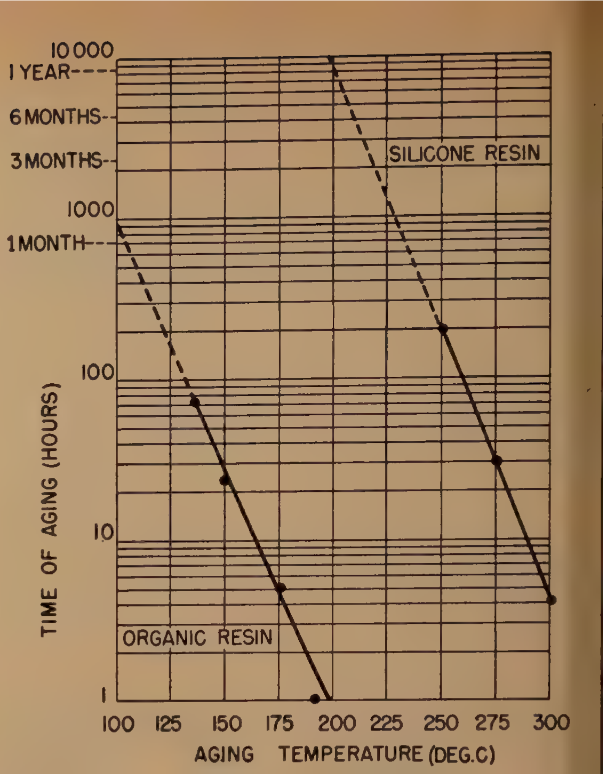


Fig. 19. Comparison of flexing life of a silicone resin and an organic resin at various temperatures. Based on reference(18)

POLYTETRAFLUOROETHYLENE

The silicone resins are not alone in their advantageo high-temperature characteristics. The polymer tetrafluoroethylene is known under the trade nam Teflon. It possesses excellent dielectric characteristics and a marked stability at high temperature.

Teflon is produced by the polymerization of gaseo tetrafluoroethylene. The product so prepared is chem ically inert over a wide range of temperature. Mold bars of the material lose not more than 10 to 20 perce

TABLE VI

PROPERTIES OF POLYTETRAFLUOROETHYLENE(17)

Density	2.1 to 2.3 g/cc
Impact strength	4 ft–lb/in.
Tensile	2000–4500 lb/sq in.
Elongation	300–400 percent
Hardness (Shore "Durometer D")	55
Flexural strength	2000 lb/sq in.
Dielectric constant	2.0
Power factor	0.0002
Dielectric strength	1000–2000 vpm
Arc resistance	>700 seconds
Volume resistance	10^{16} ohm–cm
Surface resistance	3.5×10^{13} ohms

ensile strength after one month at 300 C. At 250 C, change in tensile strength is negligible even after nths. At low temperature, even as low as −100 C, physical properties of the product are well main- ed. FIG. 20 illustrates the dielectric constant and er-factor characteristics of polytetrafluoroethylene affected by frequency. Table VI summarizes its age properties.

he engineering application of polytetrafluoroethy- appears to be limited only by its cost and the culty of its application by conventional manu- uring processes.

-LOSS RESINS

he rapid growth of the electronic industry and its ortance in the successful prosecution of World War reated an urgent demand for insulations character- by excellent dielectric properties at the higher uencies of voltage. Traditional insulations were uited for this use(18) either because of physical or ectric reasons. Synthetic chemistry has supplied the ineering answer. Polyethylene, methyl methacry- , polyvinyl carbazole and polystyrene and other n products have been developed with characteristics neet the engineering requirements.

YETHYLENE

he polymers of ethylene(19)(20) are essentially ali- tic hydrocarbons. They possess a melting point in range from 110 to 125 C, dependent on the molec- weight of the material tested. Commercial manu- ure of these products was begun in England in 9.(21) Because of its relatively low melting point, ethylene is not suited for high-temperature use. ng essentially nonpolar in nature, the material sesses a dielectric constant of 2.3 and the low power or of approximately 0.0005 when tested at a fre- ncy as high as 3000 megacycles. These dielectric perties have been the basis for extensive engineering lication of the material in the manufacture of radar ipment and as the insulation in coaxial cable. More recently, polyethylene has been applied as the insulating surface finish for watthour meter coils and in certain types of high-voltage and telephone cable.(22)

POLYSTYRENE

Polystyrene is well known for the excellence of its dielectric properties at high frequency. This has led to its extensive engineering use in applications where low dielectric loss is essential. The dielectric properties of polystyrene(23) are described by the data in FIG. 21. Like polyethylene, polystyrene is limited in its engineering applications because of its relatively low softening temperature. Operating temperatures not substantially in excess of about 90 C are its usual engineering restrictions.

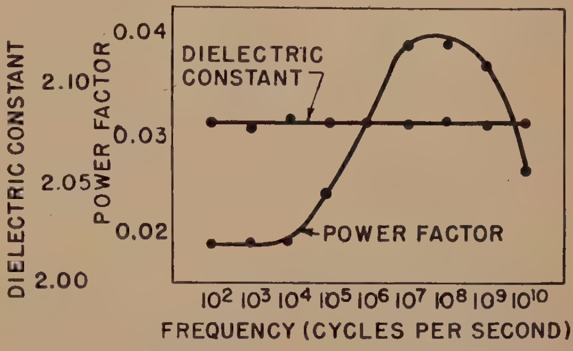


Fig. 20. Dielectric constant and power factor of polytetrafluorethylene vs. frequency(17)

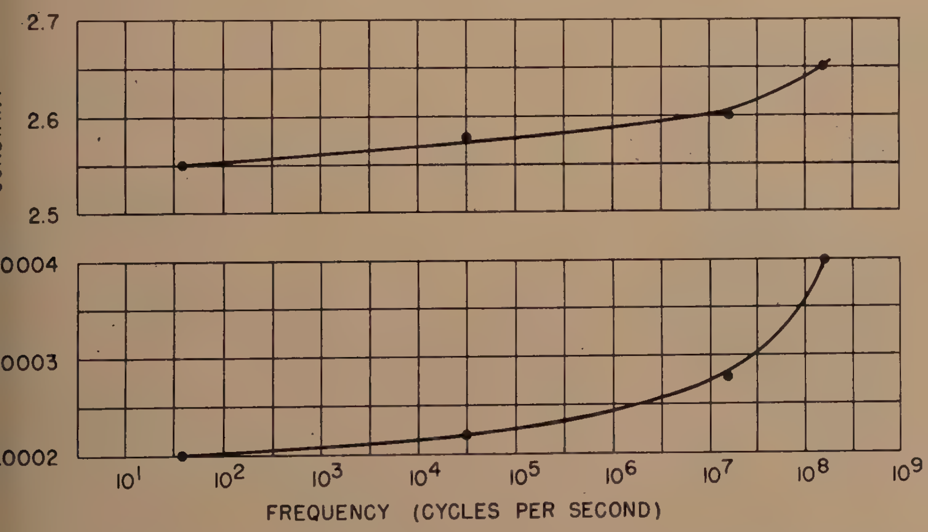


Fig. 21. Dielectric constant and power factor of polystyrene as a function of frequency(23)

POLYVINYL CARBAZOLE

Under the trade name Polectron, polyvinyl carbazole found application during World War II as a low-loss dielectric for electronic equipment. Polyvinyl carbazole has a dielectric constant of 3 which is substantially unaffected by temperature change within the usual operational limits. Its normally low power factor of 0.001 or less is not greatly affected by wide variations in the testing frequency up to 10^9 cycles per second. Polyvinyl carbazole is a hard, somewhat brittle resin at room temperature. At temperature above 150 C, it becomes tacky. The material has found engineering application as a dielectric film, as an impregnant for capacitors, and as a molding composition.

SYNTHETIC RUBBER-LIKE COMPOUNDS

Natural rubber has long been used by the engineer as wire and cable insulation. Its excellent dielectric and physical properties, however, have been offset by its susceptibility to chemical change and resulting physical and dielectric deterioration under the influence of heat, oxygen, and corona discharge. The various synthetic rubber-like compositions developed by the chemist during the past decade(24) have been widely applied by the engineer because of their chemical and physical stability under conditions which would cause severe deterioration in natural rubber. Among these various synthetics are GRS (Buna S) rubber, a copolymer of butadiene and styrene, Neoprene rubber (a linear polymer of chloroprene), butyl rubber (a copolymer of isobutylene and isoprene), Thiokol (a condensation product of an aliphatic hydrocarbon and a soluble poly sulfide), polyvinyl chloride and silicone rubber. Of these, butyl rubber, polyvinyl chloride and silicone rubber have been most widely used in dielectric applications. Neoprene has found engineering favor where superior mechanical properties are essential.

BUTYL RUBBER

High-molecular-weight linear polymers possessing rubber-like characteristics have been prepared from the simple olefin hydrocarbons such as isobutylene and isoprene. Chemically saturated polymers are not susceptible to vulcanization in the usual manner. Chemically unsaturated polymers, however, are susceptible to chemical attack. Butyl rubber has a minimum of chemical unsaturation for vulcanization but the vulcanized product is sufficiently free from chemical unsaturation to be characterized by a high degree of chemical stability under conditions which would ordinarily be destructive to natural rubber. Butyl rubber possesses a dielectric constant of 2.1 and a power factor of 0.04 percent. Although, in its initial mechanical properties, butyl rubber is not always superior to natural rubber, its marked resistance to deterioration under the influence of heat and oxidation have promoted its engineering applications (Fig. 22). Butyl rubber is widely used as insulation for electric wires and cables.(25) It has also been applied as insulation for dry-type instrument transformers.(26)

SILICONE RUBBER

Silicone rubber, like other members of the silicone family, merits engineering attention because of its high degree of chemical and physical stability at the extremes of temperature which cause severe deterioration in the properties of natural rubber and those of most of the synthetic rubber-like compounds available. The silicone elastomers show but small change in properties over a range of temperature from about −60 C to as high as 200 C and even higher.(22) The temperature stability of these compounds and their resistance deterioration traces to their silicon-oxygen structur bonding. The silicone elastomers must be cross-link by "vulcanization" in order to acquire elasticity. Th vulcanization process, however, bears little relation that commonly associated with natural rubber.

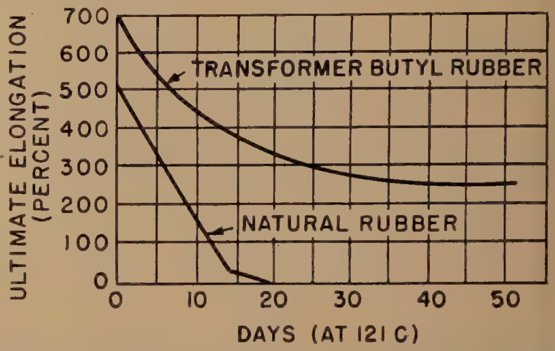


Fig. 22. Aging of transformer Butyl and long-life natural rubber. Based on reference(26). Samples 0.25 by 0.075 in. ASTM D412 elongation test, made at room temperature

The data accumulated from laboratory studies wit silicone rubber are indicative of its high order oxidation resistance.(16) Bass et al have described i superior heat-resistant characteristic (Fig. 23).

Silicone rubber is characterized by a dielectric constant which varies, with the composition of the rubbe blend, from 3.3 to as high as 9 and a power factor fro 0.3 to 4 percent. As a wire covering, the material ha exceptional heat resistance and water-proofness. It doe not undergo severe carbonization when subjected t the electric arc and is resistant to arcover "tracking."

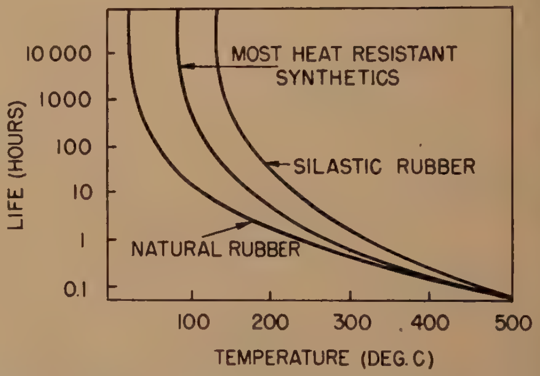


Fig. 23. Temperature vs. life of Silastic rubber, synthetic rubber, and natural rubber. Based on reference(16)

POLYVINYL CHLORIDE

Polyvinyl chloride is known commercially under variety of trade names. The compounded materia possesses a wide range of rubbery characteristics an is highly resistant to the action of chemicals an mineral oil. Its fire-resistant property has promoted it use in electrical insulation as a wire and cable covering(28)(29). Its engineering application, however, i somewhat limited because of its relatively high dielectric loss and thermal plasticity at moderately high temperature. Polyvinyl chloride is chemically and physically affected by heat and sunlight.(30) When heate

)0 C, the material hardens and evolves hydrogen ide, the presence of which catalyzes further chemi- change. The chemist, however, has developed lizers, the incorporation of which in the polyvinyl ide composition has greatly extended the useful f the product for engineering application.

SO TO THE FUTURE

emistry and electrical engineering! Just where does end and the other begin? That was not a difficult tion to answer a few years ago. The badge of istry was the test tube. The credentials of the eer were his slide rule and drafting board. But the chemist begins to share the problems of the eer and to develop products to extend the applica- of electrical machines, the bridging of the chasm een the two sciences is started. And when the eer begins to recognize the possibility of syn- zing products to meet his specific requirements, ridging is complete. This seems to be the condition existing. The co-operation between the sciences the recognition of their mutual dependence augures for the continued improvement in electrical in- ion and provides the ability of engineering to meet even more severe requirements of electrical ma- e operation in the future.

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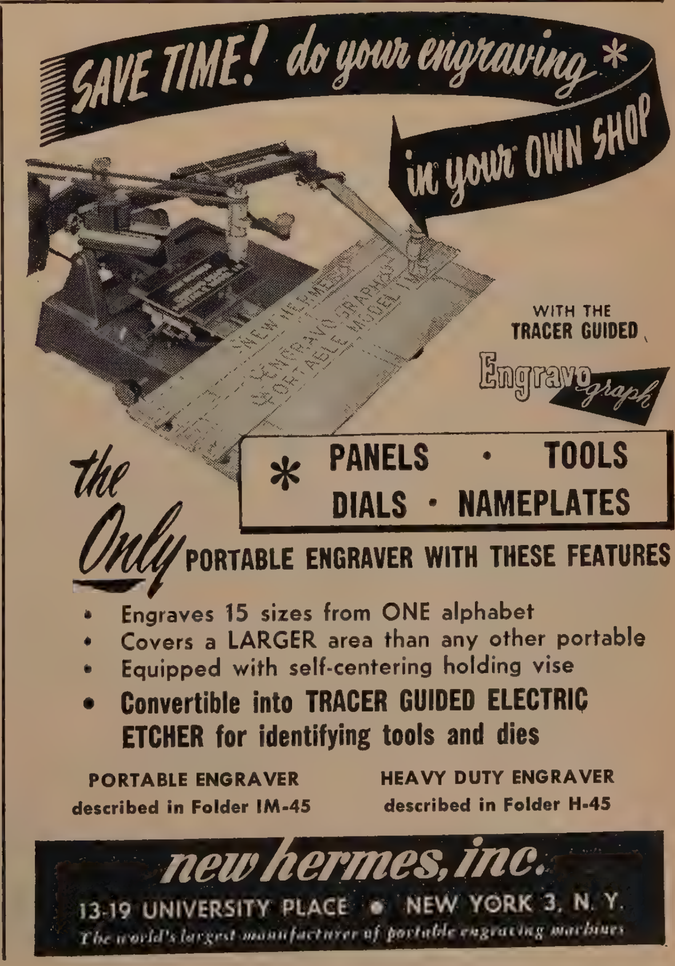

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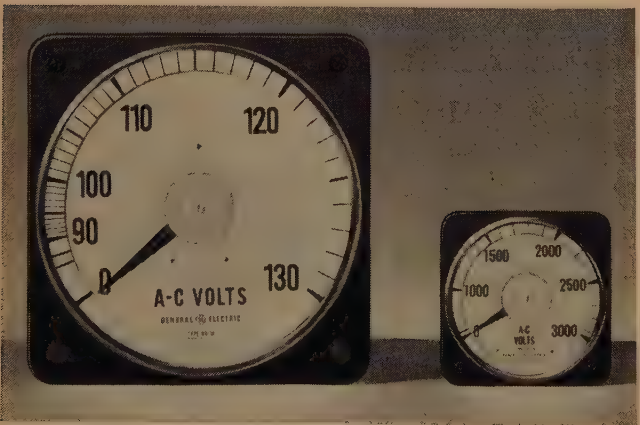

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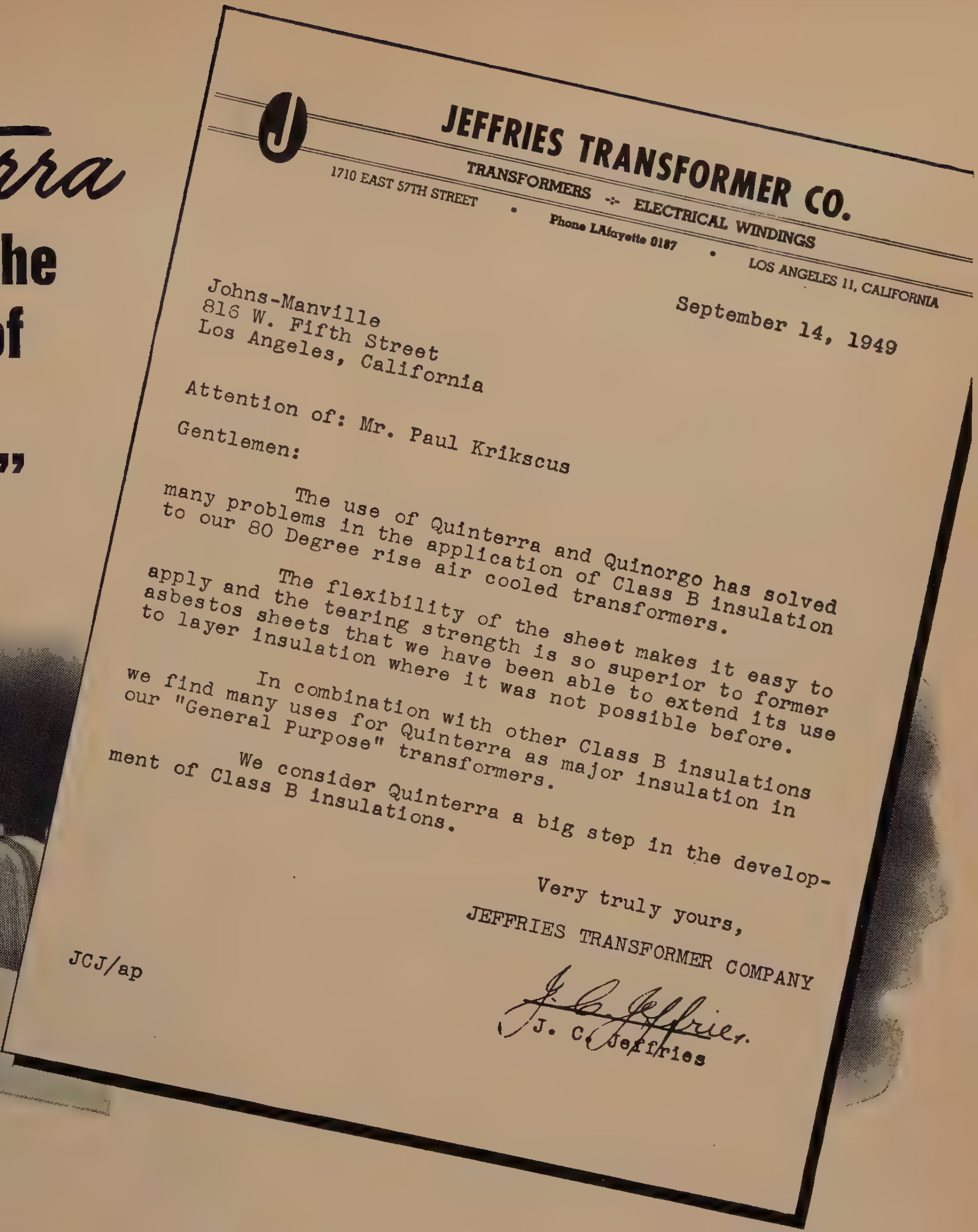

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NEW AND BETTER MOTOR BRAKE

A radically improved design of two-shoe industrial brake that includes two magnets instead of one. This and numerous other features improve operation and reduce maintenance

By THEODORE W. DRIESCH
Control Engineering Divisions, Apparatus Department
General Electric Company

Theo. W. Driesc

AFTER man had invented the wheel, he was immediately confronted with the problem of bringing to a stop whatever the wheel moved. Probably one of the earliest friction devices for retarding or stopping a wagon wheel by friction was a stick of wood held between the wheel axle and the ground. Next came some type of crude wood or metal shoe, pressed against the rim of the wheel by the pull on a handle or push on a foot-operated lever.

With the advent of the machine age, it became more important to develop brakes to retard and stop revolving machinery and the first band brake resulted. This was a steel band, with small wooden blocks attached as friction material, wrapped around the wheel, and with a long lever to multiply the force exerted by hand or foot. Sometimes instead of using muscular effort to apply braking force, weights were used but the release was made by hand or foot energy.

The later use of electric power, in the form of motor drives with ever-increasing speeds and horsepower, demanded brakes of greater capacity and reliability. Electricity then took the place of muscular effort. Improved friction materials replaced the blocks of wood. FIG. 1 illustrates such an electrical brake of early design.

DESIGN OBJECTIVES

During the past 50 years, designs have been developed with a multitude of variations in shoe or band arrangements, with one or more springs, and with numerous links, levers, and pins. The majority of those brakes had only one magnet and used a system of mechanical linkages to multiply the force of the magnet to release the shoe pressure.

The major objectives in the development of the new brake described in this article were: (1) to reduce the number of wearing parts, (2) to obtain faster operation, (3) to simplify the means of making adjustments, and (4) to have fewer parts. The first two objectives have been attained through the adoption of a short-stroke two-magnet design, which eliminates numerous levers, links, pins, and bearings. Ease of adjustment has been achieved through readily accessible screws for adjusting the magnet gap and torque setting. The fourth objective has been reached by the elimination of parts an the symmetry of the design. These objectives aim a decreased maintenance. Other advantages include improved performance and appearance. The simplicit of the new design can be noted by reference to th semisectional view in FIG. 2.

Each armature is suspended from a bearing pin whic is supported by the front and back frame castings. Eac shoe, with its lining, is mounted on its armature an supported by a spherical bearing which forms an integral assembly with the adjusting screw in the armatures. Near the bottom, facing each armature, is a magnet which carries its potted coil. The torque spring acts directly on the two armatures.

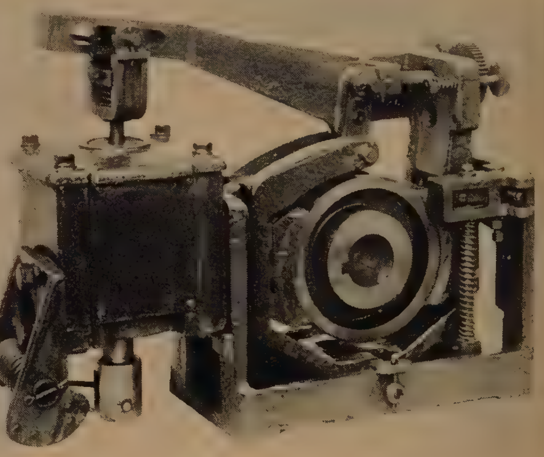

Fig. 1. Typical early design of industrial brake. It has but one magnet

TWO-MAGNET DESIGN

The use of two magnets is one of the principal feature of the new brake. FIG. 2 illustrates how the armature are utilized as levers, with only two bearing pins and one torque spring to produce the necessary pressure Two magnets result in smaller air gaps, and thereby insure faster operation.

Each magnet structure and coil assembly forms a integral unit. The coils are potted with permafil, thermosetting plastic material that is hard and tough and that will withstand much mechanical abuse. It i resistant to moisture, oil, and shock. Extensive fiel

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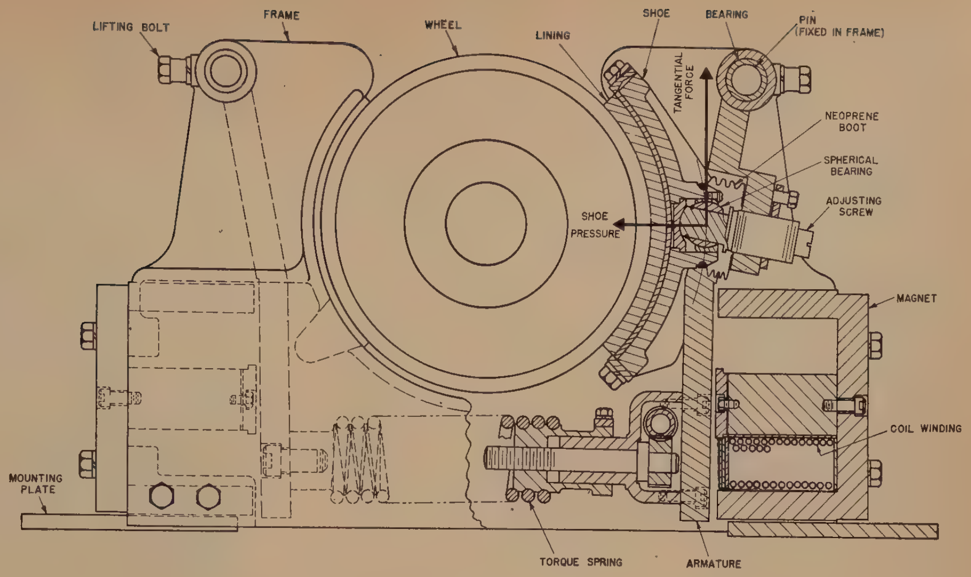


. 2. Partial-section drawing of the new -shoe two-magnet brake showing the plicity of its design

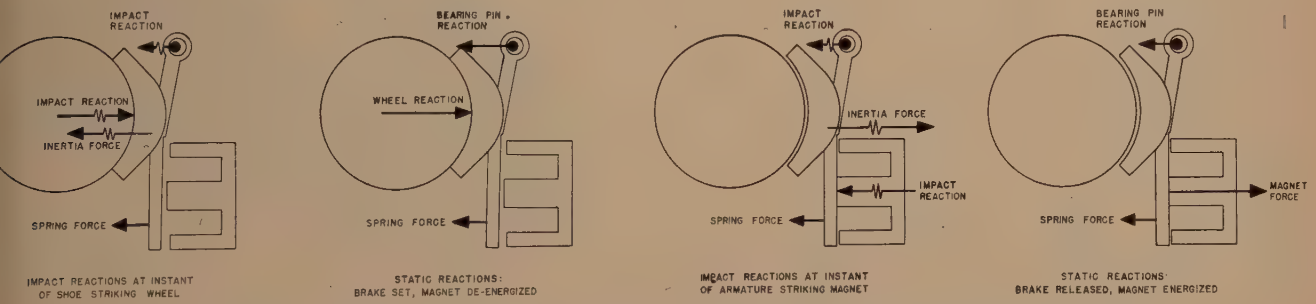
als have proved that these magnet-and-coil assemes can be used out-of-doors without special enclosures protective covers. The two shunt or series wound ls of each brake are connected in series. Power conctions to the brake can be made at either magnet.

STRIBUTION OF FORCES

The force diagrams in Fig. 3 illustrate step by step e static and the impact reactions due to spring force d magnet force. The bearing points in the armatures e made of graphited bronze bushings which oscillate hardened and ground steel bearing pins. The bearing pressure is of the order of 250 lb per sq in. at maximum load. This is conservative for the material involved and is lower than the pressures encountered in previous brake designs. The two side-frame castings provide for alignment and support of the bearing pins from which the armatures are suspended.

ADJUSTMENTS

Torque adjustments are made at the front of the brake as can be seen by reference to Fig. 4. Since brake torque varies in direct ratio to the spring length, the latter is a direct measure of torque. An indicator and a calibrated plate permit direct reading of torque setting in pound-feet.



IMPACT REACTIONS AT INSTANT OF SHOE STRIKING WHEEL

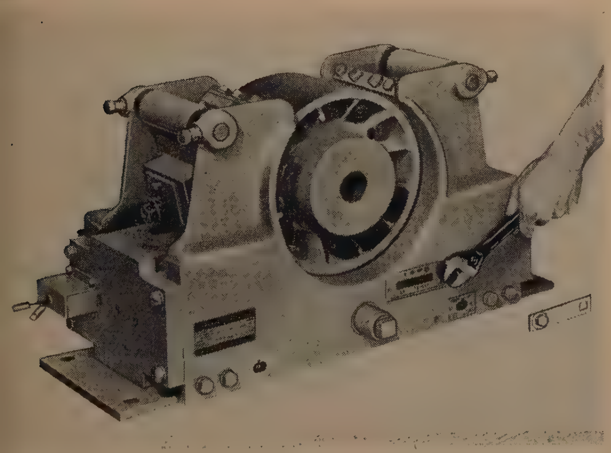
STATIC REACTIONS: BRAKE SET, MAGNET DE-ENERGIZED

IMPACT REACTIONS AT INSTANT OF ARMATURE STRIKING MAGNET

STATIC REACTIONS: BRAKE RELEASED, MAGNET ENERGIZED

Fig. 3. Schematic diagrams of the distribution of forces for various conditions (shown for one side of brake only)

Magnetic pull is a function of magnet gap, and magnet gap is a function of shoe clearance and lining wear. The magnetic pull available at a given gap has to overcome the force of the torque spring. Hence, as the linings wear, the magnet gap increases and the magnetic pull decreases. Gap adjustment, therefore, must be made before the magnetic pull drops below the spring force. The magnet gap adjustment and the lining wear adjustment are accomplished by advancing the brake shoe in relation to the armature. A gap indicator extends from each armature through the front frame and permits easy checking of magnet-gap condition by means of a gap indicating plate (Fig. 4).



g. 4. Front view showing the method of torque adjustment and the gnet-gap indicating plates

LININGS

The majority of industrial brakes use asbestos fiber as friction material. Asbestos is resistant to heat, noncombustible, and has a high coefficient of friction. Its friction coefficient and wear factor, as well as its mechanical strength, depend on the binder and other ingredients used. Lining material, is available in woven and molded form. It is necessary that the designer, in selecting lining material, also consider carefully the material of the brake wheel since proper choice of both materials is necessary to obtain optimum lining life.

Replacement of linings is an important maintenance job. In this brake each lining is fastened to a steel backing, and each unit can be slid in or out from the face of its shoe as soon as shoe pressure is released. Referring to FIG. 5, such release is accomplished by means of a manual quick-release mechanism readily accessible at the front of the brake. To provide the necessary clearance between the wheel and the shoe and to accommodate the thickness of the new lining, the gap adjustment must be backed off and readjusted after the new linings have been installed. With this brake it is therefore possible to change linings without having to remove the shoes, disassemble any other parts, or disturb the torque adjustment.

BRAKE WHEEL

The designing of the brake wheel had to take into account the strength to permit operation at maximum safe speeds; contours to allow for maximum heat dissipation both by conduction and convection; wear resistance to avoid scoring by the lining material; and low WK^2.

Vertical removal or replacement of the brake wheel and motor armature, which is necessary for crane or mill applications, can be accomplished without disturbing either the torque or magnet-gap setting. This is possible because the brake is open on top and the shoes pivot on spherical bearings which will readily tilt out of the way. When lifting the wheel, shoe pressure must first be relieved by means of the manual quick-release mechanism. FIG. 6 illustrates the ease with which the wheel may be removed vertically.

FIG. 7 shows the appearance of one of the new two-shoe two-magnet brakes with a d-c mill-type motor.

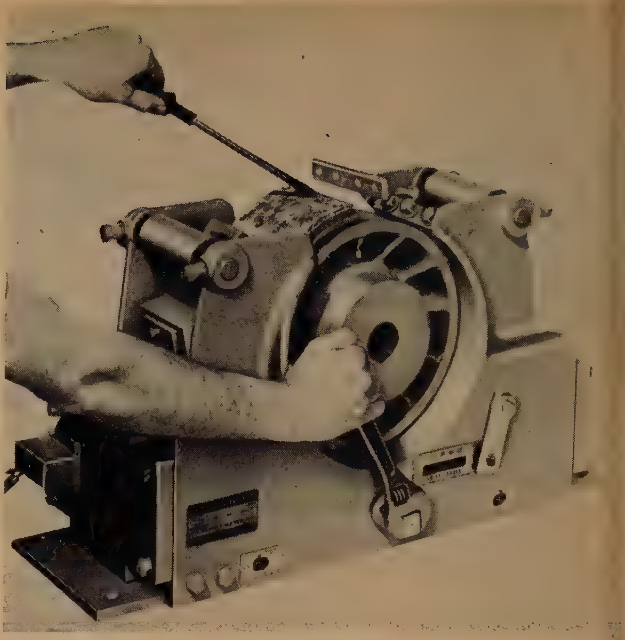


Fig. 5. Illustration of how the brake-shoe linings may be readily replaced

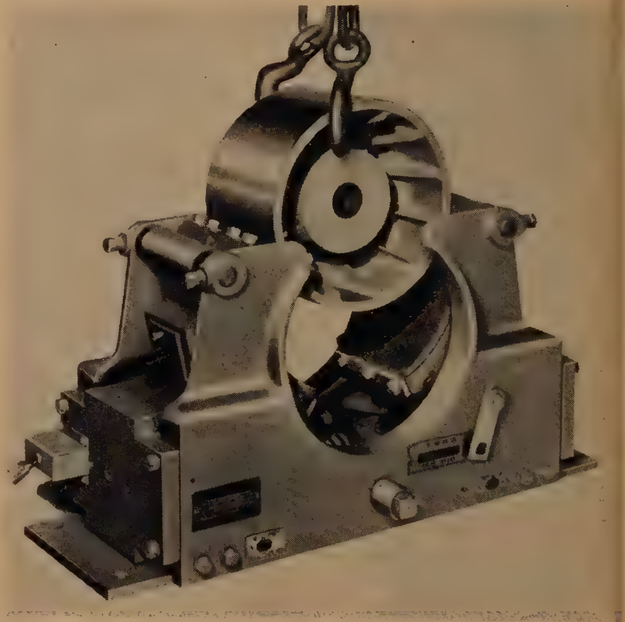


Fig. 6. The open-top construction of the brake permits vertical removal of the brake wheel

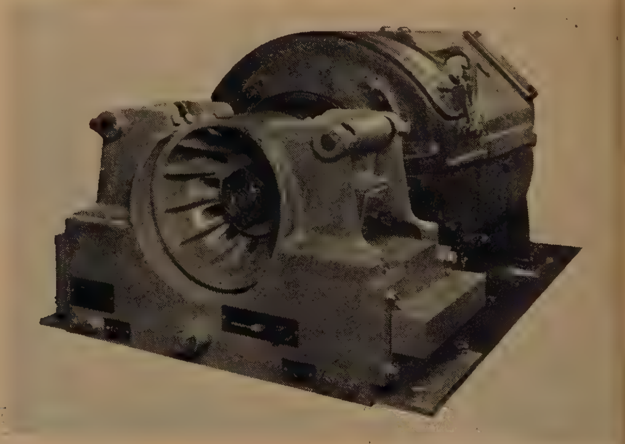


Fig. 7. The new two-shoe two-magnet brake as applied to a d-c mill-type motor

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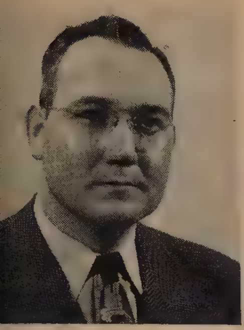
THE SCALE CONNECTION DIAGRAM



F. L. Teuscher

An accurate and completely detailed diagram in which components are shown to scale. This new representation and a wire table facilitate assembly direct from the connection diagram

By F. L. TEUSCHER and A. H. ADAMS

Industry Control Engineering Division
General Electric Company

A. H. Adams

A CONNECTION diagram is defined as one which shows the physical arrangement of devices in an quipment and the connections between these devices nd the terminals provided for outgoing connections to e external apparatus. Such a diagram is sometimes eferred to as a "wiring diagram."

Although the connection diagrams currently used for dustrial control panels fulfill the basic requirements f the definition, a number of undesirable features are herent in the diagrams and the drafting procedures sed in their preparation.

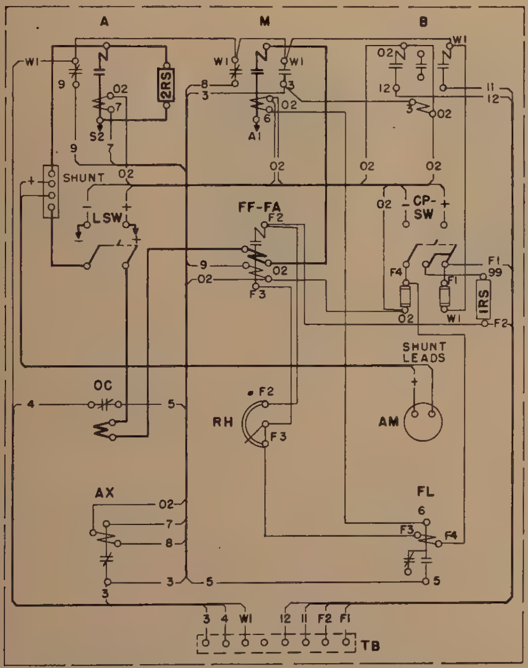
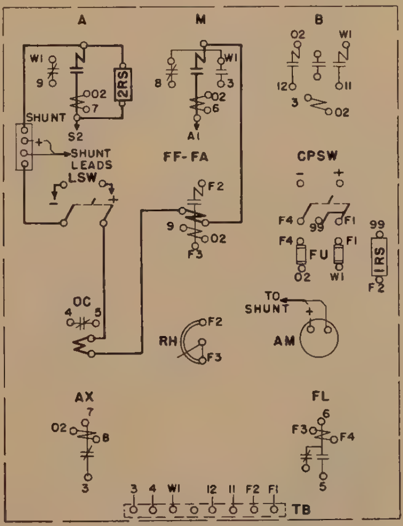


Fig. 1. Nonscale, wired connection diagram

HORTCOMINGS OF CONVENTIONAL DIAGRAM

The conventional diagram is not to scale, and the ectrical symbols are not indicative of device or comonent size. The composite symbol arrangement does ot indicate clearances or correct relative heights, and not a true picture of the actual panel layout. Distorted proportions increase the possibility of manufacturing or maintenance personnel's misinterpreting the diagram. Mechanical details are not illustrated by the symbol, which is strictly an electrical presentation that does not specify whether a connection stud or terminal is located behind or in front of the panel.

Not only is the practice of drawing each and every symbol by hand laborious and time-consuming, but the presence of the human element increases the possibility of error and tends to promote inconsistent practices. Furthermore, in order to maintain standardization, considerable effort must be expended for continuous orientation of drafting and engineering personnel on changes of product and procedures. FIGS. 1 and 2 illustrate conventional-type diagrams for a small back-wired control panel.



WIRE TABLE		
WIRE	CONNECT TO	
+		LSW, CPSW
–		LSW, CPSW
F1	TB	CPSW, FU
F2	TB	IRS, RH, FF-FA
F3		FF-FA, RH, FL
F4		FL, CPSW, FU
02		FU, M, A, AX, FF-FA, B
W1	TB	FU, M, A, B
3	TB	M, AX, B
4	TB	OC
5		OC, FL
6		FL, M
7		A, AX
8		M, AX
9		A, FF-FA
11	TB	B
12	TB	B
99		IRS, CPSW

Fig. 2. Nonscale, wireless connection diagram

SCALE DIAGRAM

A new type of connection diagram has been developed which overcomes the undesirable features of the older type by providing an accurate and completely detailed scale representation of the panel. A photographic reproduction process is employed to produce the scale diagram in less time. Mechanical as well as electrical

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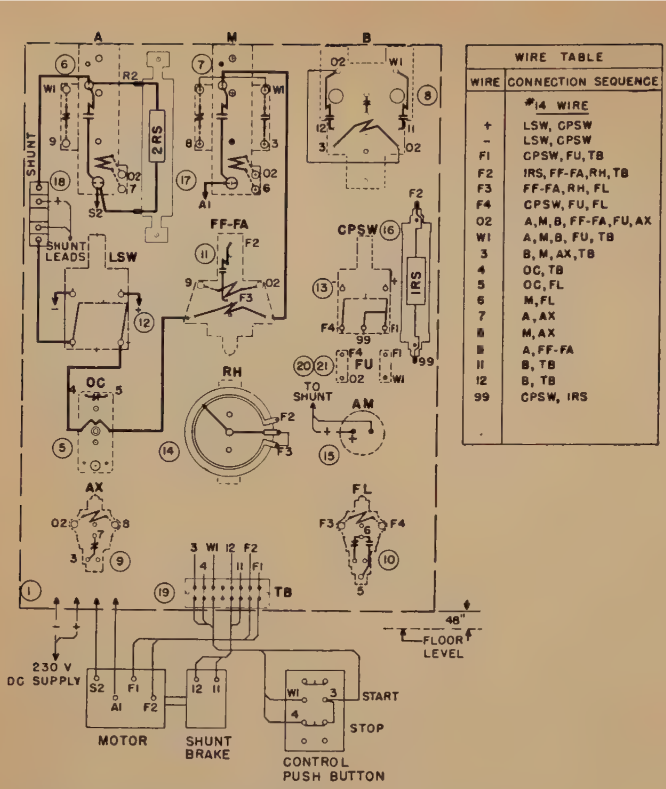


WIRE TABLE

WIRE	CONNECTION SEQUENCE
	#14 WIRE
+	LSW, CPSW
−	LSW, CPSW
F1	CPSW, FU, TB
F2	IRS, FF-FA, RH, TB
F3	FF-FA, RH, FL
F4	CPSW, FU, FL
02	A, M, B, FF-FA, FU, AX
W1	A, M, B, FU, TB
3	B, M, AX, TB
4	OC, TB
5	OC, FL
6	M, FL
7	A, AX
8	M, AX
9	A, FF-FA
11	B, TB
12	B, TB
99	CPSW, IRS

Fig. 3. Scale connection diagram with sequence wire table. (The numbers within the circles denote items in a material list.)

details are shown, materially increasing the usefulness of the diagram. Fig. 3 is a reproduction of the new scale diagram applied to the same panel shown in Figs. 1 and 2.

The major advantage of the new diagram is that the panel and its components are to scale; the arrangement and size of symbols agree exactly with the layout of devices on the panel as manufactured. Relative heights, length of wire runs, and location of studs and terminals can be scaled directly from the diagram. Positive identification and location of devices makes the scale diagram particularly useful during manufacture, installation, and maintenance.

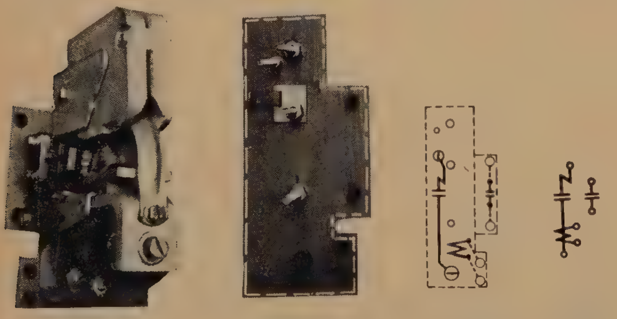

(a) Front view (b) Back view (c) New scale symbol (d) Old symbol

Fig. 4. A 100-amp mill-type d-c contactor and symbols

SYMBOLS

The new scale symbols are true replicas of the devices and components, as indicated by the close similarity between Figs. 4(a) and 4(b)—front and back views of a 100-amp d-c power contactor—and the new symbol, Fig. 4(c). The electrical portion of the symbol is always shown attached to the appropriate connection terminals. Fig. 4(c) indicates that the top and bottom power connections are respectively vertical and horizontal bars extending through lead holes in the panel. The photographs show also that the interlock and coil terminals are located in front of the panel and are wired through lead holes. The symbol portrays this information by the broken line extending from the lead hole to the solid dot designating the coil or interlock terminal. The old symbol of Fig. 4(d) does not show mechanical details. Compare the size of Fig. 4(c) with that of Fig. 4(d).

The fact that mounting as well as connection studs are an integral part of all scale symbols is of special benefit to manufacturing and maintenance personnel. Photographs of the multicircuit contactor in Figs. 5(a) and 5(b) illustrate the need for an easy method of identifying each of the various studs extending through the panel. The new symbol in Fig. 5(c) provides the answer by simple inspection. The conventional symbol in Fig. 5(d) obviously lacks such detail.

On the old-type diagram it is not practical to clearly indicate whether a device is mounted on the front or back of the panel. The new diagram overcomes this by use of solid or dotted component outlines. On back-wired panels, outlines for components mounted front of panel are shown dotted; solid outlines denote rear-of-panel mounting.

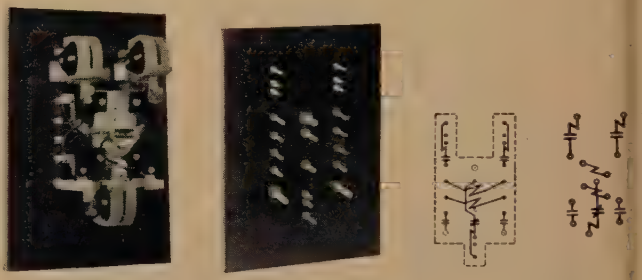

(a) Front view (b) Back view (c) New scale symbol (d) Old symbol

Fig. 5. Multicircuit d-c contactor and symbols

Fig. 6(a) shows a photograph of a small control resistor, the old symbol for which is Fig. 6(d). The dotted and solid scale symbols denoting front and back mounting applications are illustrated by Figs. 6(b) and 6(c). As these symbols are used in Fig. 3, the ammeter *AM* is shown to be front-mounted, whereas the rheostat *RH* and terminal board *TB* are back-mounted. For many equipments this feature permits panel assembly direct from the connection diagram and obviates the need for separate sketches or drawings. The encircled numbers adjacent to device symbols denote material-list item numbers.

WIRELESS DIAGRAM

The connection diagrams illustrated in Figs. 2 and 3 are "wireless" type. Power leads are drawn complete facilitate planning of heavy bus and cable runs, but control wires are shown between connection points. imination of lines denoting control wires reduces ngestion and makes the diagram easier to read. In G. 1, on the other hand, it is impossible to determine hat devices are common to a particular wire without amining in detail the many symbols and cable runs. he wireless diagram utilizes a "wire table" which is a mplete listing of all control wires, arranged in nu- erical order. Opposite each wire number are listed e designations of all devices connected by that wire. ach wire is shown on the diagram adjacent to the nnection stud or terminal on the device symbol to hich it connects. A wire run can be quickly described combined reference to the wire table and the num- ered symbols.

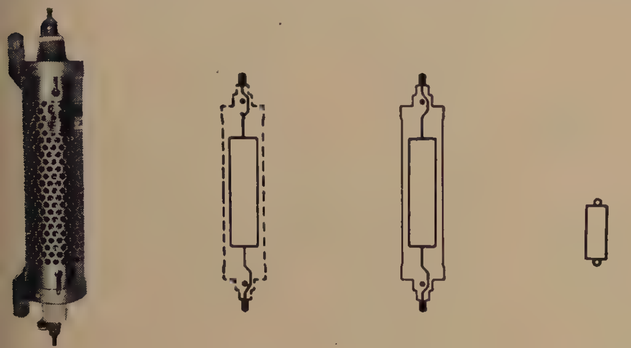

(a) Front view (b) New scale symbol (front-mounted) (c) New scale symbol (rear-mounted) (d) Old symbol

Fig. 6. Cage-type resistor

For practical reasons, short jumper wires connecting vo or more points on the same device are drawn mplete and are omitted from the wire table. This is ustrated in FIG. 3 by wire *W1*, which is common to oth interlocks of device *M*.

The "wireless" principle was first applied to the non- ale connection diagram. FIG. 2 shows how the con- ntional wired diagram of FIG. 1 has been modified substitution of the wire table for drawn control res. This type of wireless diagram has been used and cepted in industry for the past few years.

The wire table of the new scale diagram differs om that of FIG. 2 in that device designations for each re are listed in the table in their proper wiring quence—that is, the successive order in which all vices are to be connected. In FIG. 2 the device signations are listed at random; in FIG. 3, however, e connection sequence for wires such as *W1* and *O2* specifically arranged to denote the actual wire run. ne scale diagram makes this practice possible because e shortest, or optimum, wiring path is easily deter- ned by inspection. This feature is advantageous in at (1) the connection diagram prescribes to the manu- cturing organization exactly how the panel is to be red, and (2) wire tracing during installation or aintenance of the control is easier because the diagram rees exactly with the actual panel wiring.

ADVANTAGES

The many advantages of the scale connection diagram can be summarized as follows:

To the User

(1). Better diagram service—prints can be made available sooner.

(2). The wire runs as indicated on the connection diagram agree exactly with the actual panel wiring. The sequence wire table is a helpful tool for maintenance personnel when tracing circuits during trouble shooting.

(3). Device identification is more positive. The detailed scale symbol on the diagram tells the maintenance man exactly what to look for when trying to locate a particular mounting or connection stud from behind the panel. This feature is particularly advantageous to inexperienced personnel who must work on congested panel areas which are a maze of wires and studs.

(4). Inclusion of mechanical details constitutes added information not supplied on outline drawings. The scale diagram is a valuable record of the physical as well as electrical properties of the panel. If changes or additions are contemplated, the user can determine the amount of any available spare space simply by scaling the diagram.

(5). Use of the dimension denoting panel height above the floor level (as shown on FIG. 3) in conjunction with the scale panel layout enables accurate determination of outgoing cable lengths and conduit locations. Information of this nature can therefore be made available in ample time for preparation of installation drawings.

(6). Greater uniformity between diagrams for similar equipments is assured.

(7). By providing the designer with a scale replica of the product *before* it is manufactured, quality and appearance are improved.

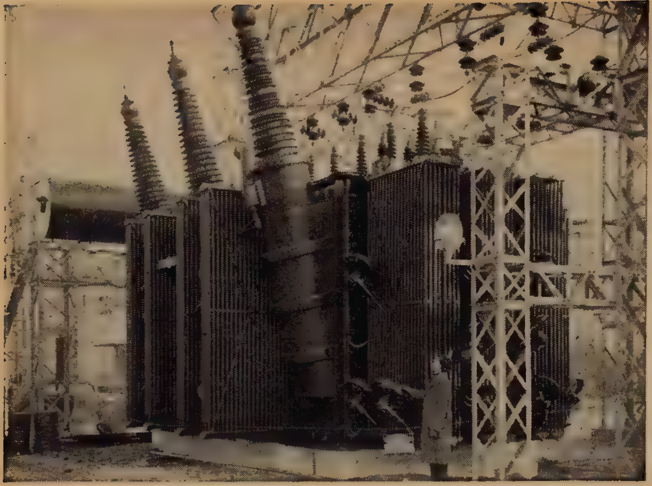
To the Manufacturer

(1). Photographic reproduction of device and component symbols requires less time and reduces human error.

(2). The scale diagram is not distorted and presents a clear picture of the equipment to be manufactured. Interpretation of engineering instructions is simplified.

(3). Prescribed wiring sequence increases the scope of the diagram, thus making it easier to achieve uniformity of wiring on duplicate or similar panels.

The photographic reproduction processes can be applied not only to connection diagrams, but also to the construction of interconnection diagrams. Symbols for the motor, brake, and push button shown in FIG. 3 are reproduced in the same manner as the panel devices. Separate and extensive interconnection diagrams also, showing the connections between panels and their external apparatus, can be produced in less time.



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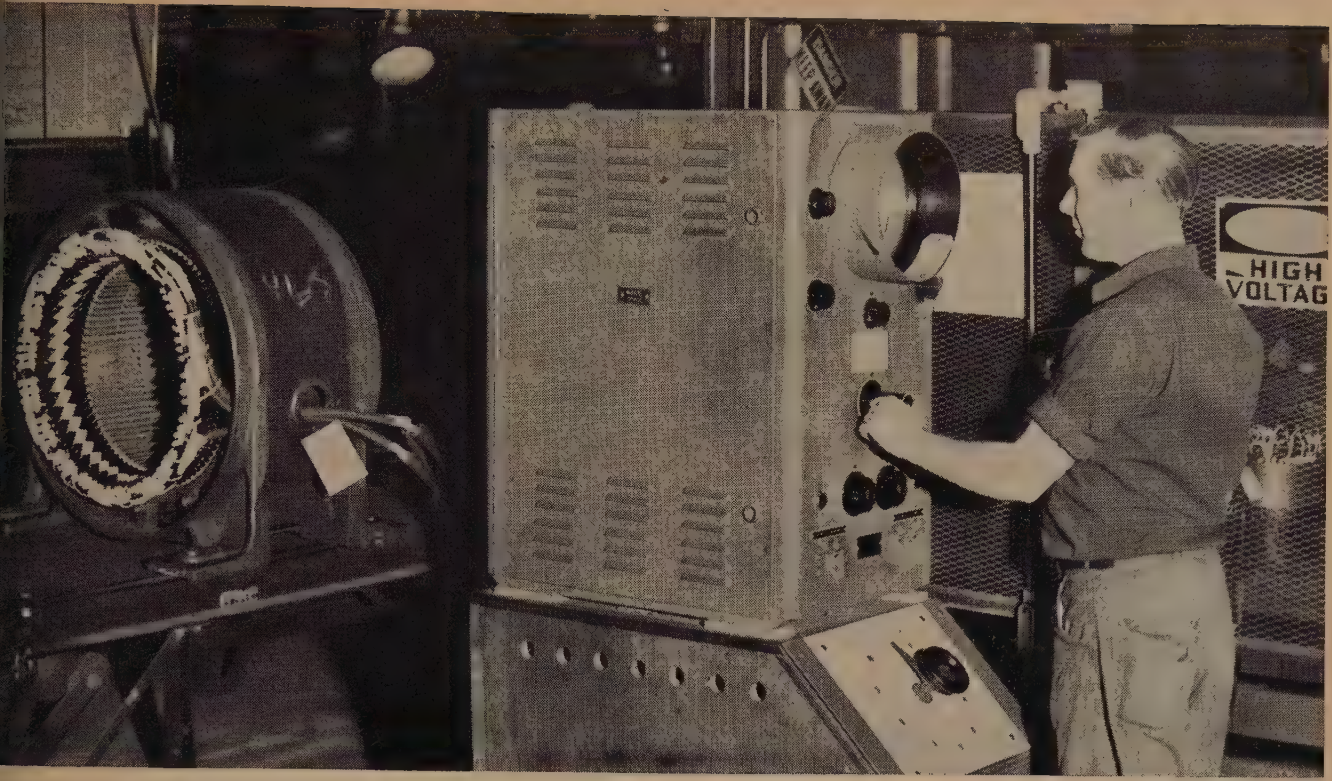

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PROGRESS IN DEVELOPMENT OF LARGE TURBINE GENERATORS

The whole complexion of turbine generator designs has changed radically in 20 years, with many changes in structure and materials, in cooling, capacity, size, and performance

H. D. Taylor

By E. D. HUNTLEY and H. D. TAYLOR
Turbine Generator Engineering Division
General Electric Company

TODAY'S designs are the products of a new generation, with some of the progress resulting from improvement and extension of principles given to us by previous generations and proof by experience of their courageous pioneering, while other departures are much more radical. It therefore seems appropriate to review the progress which has been made during the past twenty years or more. This progress has touched practically all aspects of turbine generators. In 1929, 60-cycle generators larger than about 15,625 kva rating were designed for a speed of 1800 rpm; and 62,500 kva was considered quite a large rating. All turbine generators were air-cooled, practically all being designed for closed-circuit cooling, with finned-tube coolers located beneath the generator.(1)(2) Since then, hydrogen cooling has superseded air cooling in practically all new machines for central-station service; and a tremendous growth of about 10 to 1 has taken place in the size of 2-pole 3600-rpm generators. This article gives a general survey of these changes, with a description of some of the more interesting and important design features which contribute to the reliability, efficiency, and good operation of present-day machines; and a final section deals with the continuing increase in size of 3600-rpm generators.

HYDROGEN FEATURES

The use of hydrogen as a cooling medium for rotating electrical machines has been well covered(3) to (9) previously. Nevertheless, it is mentioned here because the advantages of using hydrogen are greatest in large high-speed generators such as the turbine-driven type, and have been so well recognized that air-cooled machines are now seldom built for 60-cycle ratings larger than about 15,625 kva for use in the U.S.A. This did not come about all at once. The first hydrogen-cooled generator was ordered in 1935 and put in operation in 1937. However, even before this pioneer machine was built, many operating companies were convinced of the value of hydrogen cooling, probably because of the earlier success achieved with synchronous condensers. About 20 percent of the orders received by the General Electric Company in 1936 for turbine generators of 12,500 kva rating and larger were for hydrogen cooled machines. This percentage has continually increased, amounting to 35 percent in 1937, 50 percent in 1940, and about 90 percent in 1946. Not including 15,625 kva and smaller ratings the present percentage is practically 100. Since 1935, the Company has received orders for 450 hydrogen-cooled generators totalling approximately 28,000,000 kva rating; and 264 of these are in service (as of October 1, 1950).

The first ten years of operating experience with hydrogen-cooled generators established an extremely good record for reliability of these new-type machines. Those built by the Company all employed auxiliary equipment for vacuum treatment of the shaft sealing oil, with pumps, tanks, float valves, regulating valves, and various provisions for emergency operation in case of failure of any of these auxiliaries. This vacuum system appeared rather complex to the uninitiated, but was so well thought out and built that in 10 years' operation of all the 132 generators in service there was not a single major service interruption chargeable to the hydrogen

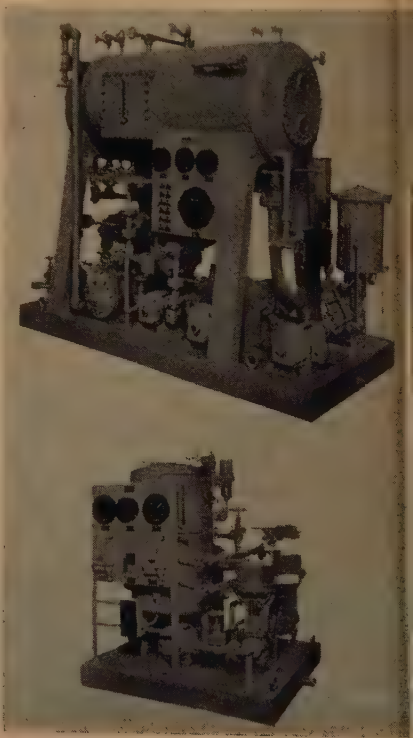

Fig. 1. Comparison of auxiliary seal oil-supply units for vacuum system (above) and for continuous scavenging system (below, to same scale)

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(1) Numbered references are listed at the end of the article.

This article was presented as a paper at the Winter Meeting of the AIEE in New York City on January 26, 1951.

This article is so paged that, without mutilating other articles, it can be readily removed for filing as a group of full-size consecutive pages.—Editor tures. This does not mean that all the auxiliaries rformed perfectly all the time; but, rather, that such oubles as did occur were of a relatively minor nature, d had been backed up in such a way as to avoid the cessity for taking the generator out of service. In the th year, this record was broken, and a service outage curred on one machine because of a succession of ents, starting with leakage of air into the main seal pump caused by loose bolts on the pump suction nge, and including failure of some alarm devices to nction properly, and misoperation by the station rsonnel. Such combinations of circumstances are ite rare—which serves to emphasize the reliability the vacuum system of hydrogen auxiliaries when operly installed and operated.

A new simplified hydrogen system was developed seval years ago by the company, and has been used on a nsiderable number of machines. This is known as e "Continuous Scavenging System," which has been scribed recently.(10) It does away with the use of cuum-treated oil, and materially cuts down the numr and size of the auxiliaries, so that the operation is eatly simplified, and the floor space required for the xiliary equipment is materially reduced. A comparin of the sealing oil auxiliaries for the older vacuum eating system and the newer continuous scavenging stem is shown in FIG. 1. Operating experience has oroughly proved the reliability of the new system. is now a standard feature on all but the largest sizes new hydrogen-cooled turbine-generators, and will obably be used on them also within another year or o.

PROVEMENTS IN VENTILATION

Internal ventilation of turbine-generator fields was a jor improvement of the 1920's. In those days this ntilation was arranged to flow axially inward from e ends of the rotor through subslots or tunnels just derneath the field-coil slots, discharging radially rough holes drilled in the teeth between the field ls. In the 1930's an improved type of ventilation was plied to the larger two-pole rotors then being deoped, wherein the tunnels or subslots were superled by narrow ventilating slots cut directly in the th and closed by small wedges through which disarge holes were drilled, in the central portion of the or. These tooth-ventilation ducts had a double adntage over the tunnels, in that they provided a more ect path for the flow of heat from the field coils into e ventilating ducts, and also relieved the mechanical ty on the roots of the teeth, caused by centrifugal ce, so that more copper could be carried in the field ts for the same limiting tooth root stress. This conuction was particularly adapted to use in two-pole signs on account of the more pronounced taper of the th as compared with four-pole machines. A more ret improvement in rotor ventilation employs both slots and tooth ventilation ducts as is shown in . 2, which shows a representation of a section of a erator-field structure. This arrangement practically surrounds the field coil with active ventilation so as to achieve a minimum temperature rise, together with improved uniformity in the radial distribution of the temperature in the various turns of the field winding. The advantages of this construction are fairly obvious—so much so that it was suggested repeatedly by many different designers. It was not adopted, however, until one of them devised a suitable means for discharging the ventilating gas from the tunnel without unduly impairing the strength of the tooth root structure. This is accomplished by drilling a number of radial holes in the central part of the rotor down from the ventilating slot in each tooth deep enough to be alongside of the subslot, from which a matching hole is drilled circumferentially to meet it.

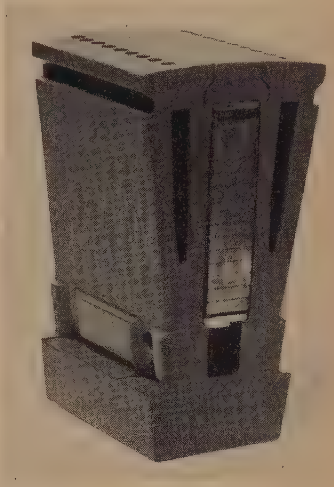


Fig. 2. Representation of field structure showing combined tooth duct and tunnel ventilating system

One of these circumferential holes can be seen in the near corner of the model shown in FIG. 2. It will also be observed that the subslot has been widened at this spot by means of a radial drill of the same diameter as the width of the main coil slot. Many visitors at the factory become highly curious as to how this circumferential hole is drilled near the bottom of a fairly deep slot. It is really quite simple, as the drilling device consists of a train of spur gears carried between two steel plates, and driven by a motor. This assembly fits down into the slot with a considerable clearance; and the bottom member of the gear train carries a small end mill projecting from the side of one of the supporting plates. The whole device is arranged to swing on a set of pivots located in a framework which clamps to the surface of the rotor, and the hole is drilled simply by starting the driving motor and swinging the assembly so that the end mill cuts through at the proper place near the bottom of the slot. Anticipated difficulties with this operation did not materialize, and this construction has now been used for several years. It is particularly adapted to the larger-size 3600-rpm 2-pole generators, where the radial depth of the copper field coils is somewhat limited by mechanical considerations.

Propeller-type fans have long ago been found to be better adapted to the very large 3600-rpm generators than the older centrifugal fans, partly because they are more efficient, but also because the inlet conditions

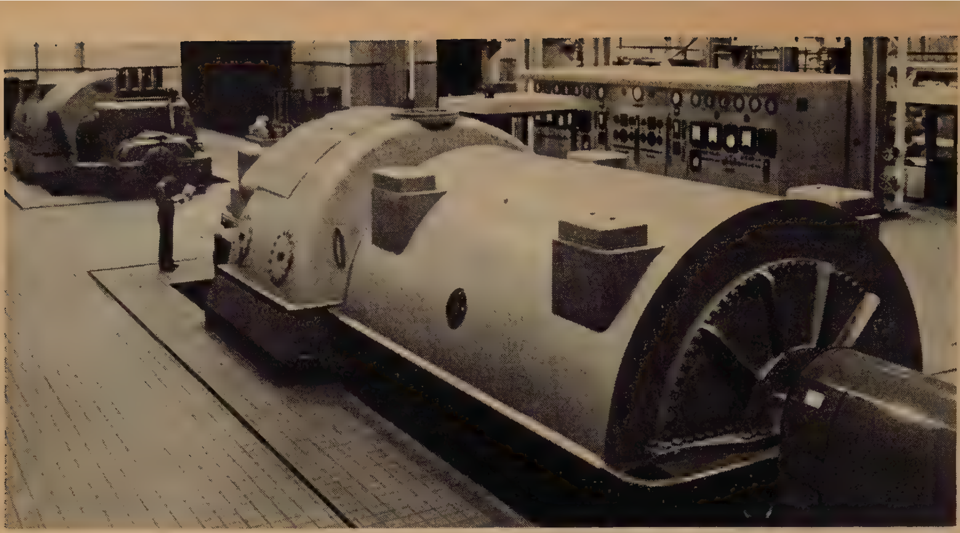


Fig. 3. Hydrogen-cooled turbine generator with welded steel plate end shields having removable bearing caps and access ports; also shown is the vertical cooler arrangement

are more favorable and a more compact design can be arranged. The centrifugal fans require that the inlet gas must flow through an annular opening between the shroud ring and the shaft, which is a very serious limitation in large high-speed generators. With propeller-type fans, however, there is no such limitation. For these reasons, propeller fans have been standard now for quite a number of years on the larger 3600-rpm generators. One difficulty with them, however, was observed and corrected when they were first applied. This is the matter of the distribution of the total ventilating flow among the various parallel circuits of the multiple radial ventilating system, which has long been standard.

The axial discharge from the propeller fans quite naturally favored the circuits through the ends of the machine (directly into the air gap) at the expense of the circuits employing inlet sections in the central part of core structure. This is in contrast to the tendency of the centrifugal fans, with radial discharge, which favored the core inlet sections. This shift in distribution of flow of ventilating gas caused by changing over to propeller type fans was readily corrected by the use of baffles, and as this was provided for on the first hydrogen-cooled generators employing propeller fans, no difficulties have resulted. As a matter of fact, very complete tests on this point were carried out in a special half-scale setup, which was operated with propeller fans over a period of a year or more with various combinations of duct and fan and baffle arrangements. The results of these tests are quite detailed and are beyond the scope of the present article. However, the work may be summarized by stating that optimum arrangements were determined and have been used to advantage in design of ever larger 3600-rpm generators.

These developments in the ventilation of both stator and rotor have been most fruitful, as the temperature rises of the windings in new generators which have been designed to take advantage of these improvements have proved to be very conservative. This will be touched upon further in the last section of this article.

MECHANICAL IMPROVEMENTS

Most of the earliest hydrogen-cooled turbine generators employed heavy split cast-steel end shields, designed both to withstand possible explosion pressur safely, and to support the main bearings. Such castin proved to be rather expensive and were often porou and much trouble was experienced in their manufactur with defects which frequently were not discovered unt the parts were nearly finished, so that extra costs ar annoying delays were caused by the necessity of maj repairs. In addition, it was a tedious and fussy job fit the top and bottom half shields together in such way as to make a gas- and oil-tight joint, and at the sam time to clamp the bearing properly. A major improv ment was made several years ago by changing over fabricated construction of the end shields, using welde steel plates. This eliminated the casting troubles com pletely. At the same time, the basic design was change in several ways. Inspection holes with readily removab cover plates were provided in the top half shields, f convenient access to the inside of the machine at eac end. Separate bearing caps were made, apart from th top half shields, so that the fitting of the shields an bearings was greatly facilitated. Also, the hydroge seals were divorced from the bearings and mounted c the shields, so that with this construction it was possib to roll out the bearings for inspection without removin the top-half end shields, and without purging the ge erator casing of hydrogen. This type of shield con struction is illustrated in Fig. 3.

An annoying characteristic of many of the larg early 3600-rpm generators was the magnetic double frequency vibration, caused by elliptical distortion c the stator core and frame by the magnetic pull of the pole rotor on the inside of the core. This vibratio appeared and disappeared as voltage was built up c reduced on the armature winding. It was usuall communicated to the machine foundation and adjacen parts of the power station, such as beams, floor plates instrument panels, gages, etc.; and the resulting vi bration and noise were often disagreeable and occasion ally destructive, especially if there happened to be condition of vibrational resonance which resulted i magnification of the rather small amplitudes trans mitted from the machine. This magnetic core vibratio is isolated from the frame in modern machines by a

stic core suspension, as has been described pre-
usly,(11)(12) so that it is ordinarily impossible to tell
touch or by ear when excitation is applied. Another
pe of double-frequency vibration, independent both
excitation and mechanical balance, has occasionally
own up on the machine bearings or on overhung
rtions of the shaft, such as the collector. This is
sociated with the slight difference in the bending
ffness of the 2-pole rotor between the polar axis and
e axis through the slotted region of the field body,
ich may give the rotor a tendency to rise and fall
er so slightly twice per revolution.(11)(13) In the authors'
perience, this "mechanical double-frequency" vibra-
n of the rotor has been much less serious than the
gnetic vibration of the stator core, and has never
used any serious operating trouble. In fact, it has
dom been large enough to be noticeable, and then
ly in cases involving mechanical resonance of the
ole machine and foundation structure. Since these
ses of resonance are practically impossible to predict,
has become standard practice on large machines to
luce the stimulation by partial compensation of the
quality of the field body stiffness so as to insure
ooth operation within fine limits in all cases.

An improved arrangement of the hydrogen gas coolers,
ounted inside the generator frame, gives a number of
vantages, as compared with older designs usually
ploying four coolers running lengthwise of the gen-
ator. Vertical coolers, mounted at the four corners of
e machine, as shown in FIG. 3, permit a simpler,
onger, lighter frame design, and facilitate manu-
ture, especially with respect to cleaning out chips, etc.
t, more important, this arrangement makes it easy
keep the cooler water-boxes, gaskets, and all piping
tside of the gas space, thus eliminating several pos-
le sources of troublesome water leaks inside the
erator. Also the piping is arranged below the operat-
floor, out of the way. And the coolers can much more readily be assembled or removed, simply using light crane facilities. Very large machines may employ 6 or 8 vertical coolers, as in FIG. 4.

IMPROVEMENTS IN INSULATION

There are three major insulating functions in large turbine generators: (1) insulation of the relatively low-voltage d-c field windings, which must stand up under severe centrifugal loading and thermal expansion; (2) insulation of the high-voltage a-c armature coils, which have no centrifugal forces but are subject to thermal expansion stresses and must withstand severe mechanical shocks and occasionally voltage surges at times of system disturbances; and (3) insulation of the segmental core laminations against eddy-current losses and heating. Significant improvements in all of these insulations have been made in recent years.

Mica tape made with a copal-type varnish and applied with shellac was the standard turn insulation for turbine generator field windings for many years prior to the rapid increase in size of 3600-rpm machines, beginning in 1935. This tape proved to be inadequate to withstand the increased centrifugal pressures in the large 3600-rpm fields designed with copper windings (although it was quite satisfactory with aluminum windings), and it was superseded between 1935 and 1940 by two improved insulations: (1) hard-pressed sheet mica of high quality containing very little binder, used as a separator between turns; and (2) a glass-cloth-backed mica tape made with a synthetic resin-base varnish. These were both used for a period of years, the separators on the larger machines, and the tape on the smaller ones. It was recognized that the separators were advantageous in the slot region, giving a better space factor; and the tape was advantageous for the end portions, as it would stay in place better, although both had been found quite satisfactory in service in both regions. Present practice on all of the

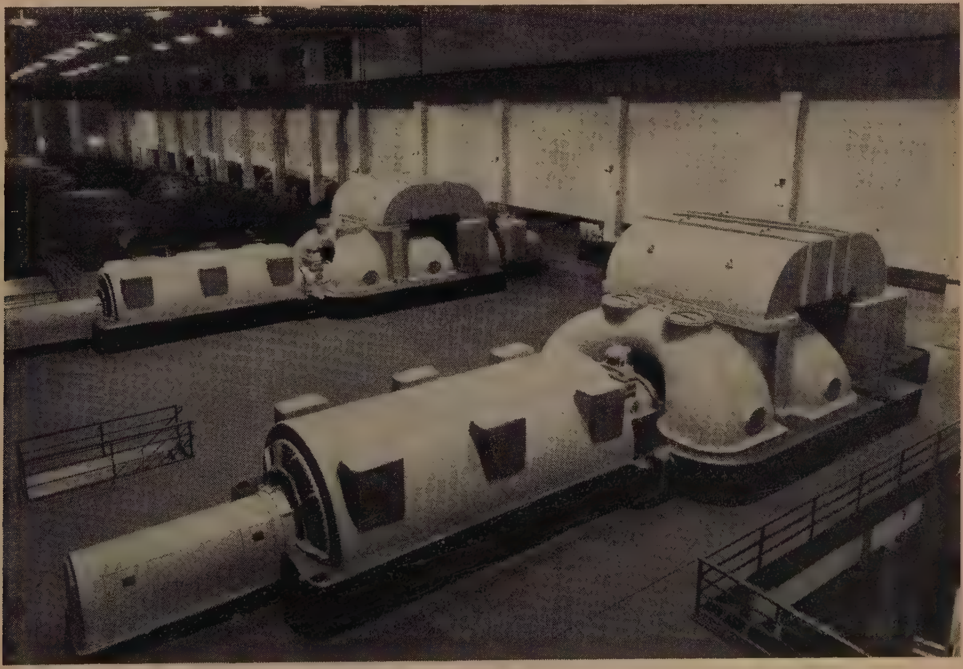


Fig. 4. Two 125,000-kva 1800-rpm hydrogen-cooled turbine generators, each with six vertical coolers

larger machines employs the logical combination of double separators in the slots and tape around the ends, the tape being applied to alternate turns and enclosing single separators.

This turn insulation has been proved both by severe laboratory tests and by many years of service to be completely reliable. Less drastic changes have been made in the ground insulation for field windings, consisting of molded U-shaped armors for the slot region made of sheet mica protected by asbestos cloth, all impregnated with suitable varnishes to give the desired strength and toughness. The varnishes have been changed to synthetic types; and a thin protective layer of glasbestos cloth (made of a combination of glass and asbestos fibers) has been added on the inside of the U, so that the mica is now sandwiched between protective coverings. The previous slot armors have been virtually free of trouble for many years, and the new ones are even better. At the ends of the coils, where the entire coil sections were previously taped with half lapped layers of mica and asbestos tapes, the coils are now left bare for improved ventilation, and the ground insulation consists of a cylindrical ring between the coils and the retaining ring, molded of mica and asbestos cloth like the slot armors. The coil ends are separated from each other and blocked securely in place both axially and circumferentially by accurately fitted insulating blocks, made of asbestos-cloth-base Textolite®. This construction is illustrated in Fig. 5, which also shows the large-radius corners of the field coils, which permit thermal expansion to take place without excessive bending stresses in the coil material.

Reliability in service has been an outstanding characteristic of the high-voltage insulation used for large turbine-generator armature coils. The annual Edison Electric Institute report, showing the outage hours credited to various causes, reveals that over the years 1940 to 1947 (the last year reported), machines were available for operation, as far as armature insulation is concerned, 99.871 percent of the demand time. Expressed in another way, armature insulation has been available for service 799 out of every 800 machine operating years. No failures connected with "girth cracks" or "tape separation" have been experienced in any hydrogen-cooled machines. It is believed that this record has been achieved by virtue of a program of continual improvements in the methods of applying this insulation. Such changes as better asphaltic-type varnishes and compounds, more exacting manufacturing techniques, more searching methods of inspection, and the application of quality-control methods have continually raised the mechanical and dielectric characteristics of the finished coils.

With regard to manufacturing, the sequence of the compounding operation has been changed in such a way as to produce a denser, more completely filled coil. Molding operations have been modified, obtaining a marked increase in dielectric strength. Handling operations in the shop have been safeguarded in many ways, eliminating accidental damage during manufactu
New inspection routines have been established
increased testing facilities provided to continua
check and control earlier operations. New materi
include an improved vertical separator, serving as
insulating bond between the two tiers of strands in
Roebel type transposed bars or half coils, the separa
being made of glasbestos cloth (glass and asbest
treated with a synthetic varnish which is excellent bo
as insulation and as a binder. On the surface of the s
portion of the coils, a coat of moderately high-resistan
varnish is applied for corona protection, supplement
at the ends outside the core by a much higher-resistan
coating which serves to taper off the potential gradie
and minimize any concentration which might cause d
charges. Perhaps the most important change in ma
rials has been the elimination of Class A insulati
materials formerly used, such as cotton tape, fi
fillers, linen cord, cambric tape (on loops, connectio
terminals). These have been replaced by Class
materials—glass tape, asbestos fillers, glass cord, gla
backed mica tape, etc.—so that the winding can realis
cally be called Class B throughout, from terminal
terminal. With these new features, the reliability
high-voltage insulation on the stator coils of large tu
bine generators can be counted upon to be even great
than would be indicated by the excellent records set
the past years.

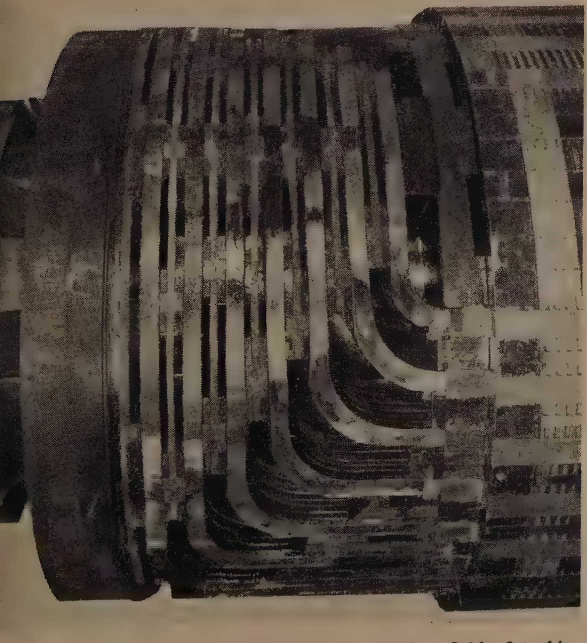
Simultaneously with these improvements, extensi
laboratory work on the use of new insulating materia
has been carried on. In spite of all this work, mica r
mains the backbone of high-voltage insulation. Ho
ever, new stickers and compounds and new forms of mi
give considerable promise for the future. A number
the most promising combinations are now undergoi
severe tests. In view of the excellent performance
presently used insulation, and the very small percenta
increase in machine availability obtainable even with
perfect insulating system, it is felt that new insulatio
must undergo the most rigorous testing procedures, an
even more important, must prove themselves in actu
service on suitable machines before risking the re
ability of many major units. In short, an insulatio
change should be an evolutionary process, not
revolutionary one.

Major improvements have been made in core-pla
enamel within the last decade, and the flash process
applying it to the punchings of turbine generators h
been superseded. In the first place, the somewhat roug
pickled surface of the sheet-steel punchings themselv
has been made comparatively smooth by a special col
rolling operation which is carefully controlled to avoi
increase of magnetic losses. This is a basic improvemen
as it is next to impossible to put a good thin insulatin
film on a rough pickled surface. Secondly, a new type
enamel is used, made of a thermosetting synthet
resin, mixed with a considerable percentage of inorgan
material—finely divided silica particles. When proper
baked, the enamel "sets up" and thereafter cannot

ned by any amount of heat, even to the extent of ing it off. And even if it should be deliberately ed off (as is done regularly for test purposes on le punchings) there is a residue of silica which forms y effective insulating barrier or firewall. Thirdly, baking-type ovens have been provided for applying ew enamel, with adequate controls to insure proper ng to produce a hard tough film. Finally, inspection iques have been greatly improved, and the quality e finished punchings is controlled by insulation on frequent samples of the actual punchings, under and pressure conditions more severe than exist in ce. This enamel does not absorb moisture, as do ght inorganic films such as water glass, and organic made of cellulose paper; and it has such excellent ating properties that no supplementary insulation eded in the core. Its heat-resistant properties are so that it has been used successfully in special high- erature cores for small motors and generators in h silicone-insulated coils have been capitalized for ction in dimensions and weight.

OVED FIELD COIL MATERIALS

e need for improvement of the mechanical strength ld coils in large turbine generators was recognized ifferent generator designers in this country and in pe at different times, depending upon their ex- ence with and observations of difficulties arising the thermal expansion of field coils in large ines, particularly machines which were frequently ed and started. There have long since been enough difficulties, resulting from distorted coils, grounds, short-circuited turns, so that the problem has been recognized, and quite well covered by previous les(14) to (17). However, for greater clarity, a brief ment of the problem is included. It was universal ice for many years to employ ordinary soft annealed copper for the field coils of turbine generators. Large machines require rotating fields of great length and considerable diameter, subject to high centrifugal forces. The centrifugal forces tend to clamp the field coils against wedges carried in the solid-steel field body, in such a way as to restrain them at least partially against thermal expansion relative to the body. In normal operation, a machine is brought up to speed after a shutdown with the field winding and the field body at about equal temperature, possibly room temperature if the shutdown has been of considerable duration. When carrying load, the coils tend to expand considerably more than the field body, partly because of the difference in temperature between the copper and steel corresponding to the thermal drop through the insulation, and partly because of the higher coefficient of expansion of the copper as compared with the steel. As a result of this differential expansion's being largely restrained by the friction imposed by centrifugal force, a considerable compressive stress is built up in the coil material, which might easily exceed the elastic limit of the copper; or possibly the coil might tend to buckle in some way. Generally, the coil does not buckle, but instead the material may be upset in compression, in such a way that when the machine is shut down and allowed to cool off, the entire coil (or the warmer turns of the coil) contracts slightly, suffering a permanent plastic deformation. With successive cycles of service—starting, carrying load, and stopping—the coil or some of its turns would start each time from a new position, and would suffer progressive contraction, which in time may be enough to cause serious trouble.



5. Close-up view of end portion of revolving field of turbine rator with retaining ring removed to show ends of field coils

Two fairly obvious solutions to this problem were apparent: (1) to change the operating procedure in such a way as to expand the coils prior to their being clamped by centrifugal force; and (2) to produce field coils of sufficiently high mechanical strength to stand up under the compression stresses resulting from the restrained thermal expansion, without being upset, or suffering from creep or relaxation effects. Both of these proposed solutions have been studied at length, and have been proved to be effective. The first one which involves "preheating" of the field coils before the machine is brought to speed was the subject of a paper(15) presented in 1944. Later experience with one of the very large generators referred to in that paper, which has been regularly preheated, has been very good. This machine had the largest two-pole rotor in the world, and was wound with coils made of soft copper. It has carried heavy loads and has been shut down frequently over a period of 6 or 7 years but has been preheated regularly on starting without suffering appreciable deformation of the coils. Previous experience with this machine with similar operation over a period of only two or three years without preheating resulted in severe deformation. It seems clear from this experience that preheating, properly carried out, is definitely beneficial. Preheating has been recommended on quite a number of other machines on which experience is being accumulated.

Also much analytical work has been carried out to interpret observations on these machines, and to help determine the best procedures.

Improved mechanical strength of field coil material without appreciable sacrifice of electrical conductivity appeared to be a more generally acceptable solution to the expansion problem; and for this reason a broad research program was initiated, in 1944, to explore the possibilities of adding various alloying elements to copper or to aluminum. Aluminum had been used to some extent in large 3600-rpm generators, but had proved to be more plastic than the soft annealed copper. With regard to copper, the beneficial effects of small fractional percentages of silver had been recognized by 1940, and silver-bearing copper, so-called, was in regular use on large turbine generators. The silver helped the copper in two ways: first, by a marked increase in the rupture strength, as a function of sustained stress at a moderate temperature over extended periods of time; also the silver made a marked increase in the recrystalization or annealing temperature of the copper, so that the effect of moderate cold work in raising the yield strength of the copper would not be lost over a period of years at operating temperature. The research program was intended to search out other alloying elements which might be even better for copper-base field coils; and also to find some way to improve aluminum correspondingly.

The work in the Research Laboratory was supplemented by evaluation tests conducted by the Works Laboratory with active co-operation of Prof. M. F. Sayre of Union College. The apparatus used for these valuation tests is shown in Fig. 6. This includes a series of cylindrical ovens arranged to be heated automatically to temperatures in the range of 100 to 150 C, with automatic control for maintaining constant temperature as desired. The tests were run in compression, because the basic problem in the generator field was one of compression rather than tension, and we had reason to believe that the compression properties were not necessarily the same as the tension properties. The technique of compression testing was distinctly novel, and was developed especially for this research program. Little emphasis has been given to the matter of creep or relaxation effects in previous papers on this subject. However, it seemed fairly clear that if alloyed conductor materials could be developed to have the required yield strength on a short-time basis, even though measured at operating temperature, nevertheless the compression stress resulting from the restrained expansion in service at full load would be considerably higher than would be the case with soft conductor materials, so that over long periods of time creep or relaxation would surely be an important item. The tests as actually carried out, therefore, included room temperature stress-strain curves in compression, operating-temperature stress-strain curves, and compression creep tests. Altogether a great mass of data have been obtained, which were most valuable and informative.

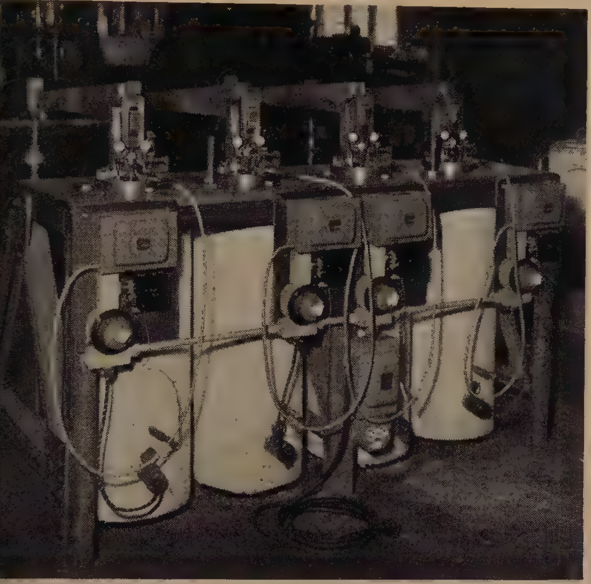
As to the new materials which have come out o research and development work, the evaluation o silver-bearing copper which was in use when the gram started has shown that it is an excellent and hi satisfactory material for use in even the largest ma under construction at present. Among the other a ing elements which might be added to copper to prove its properties, no others were found as goo silver except cadmium which tests indicate woul somewhat better. It may be recalled that cadmium used long years ago as a hardening alloy for us trolley wires. The project for an improved alumi material appeared much more venturesome at the set, but has been richly rewarded. The metallur story has been published.(18)

In brief, eleven different elements were tried ou additions to pure aluminum, and their effects meas as to conductivity and mechanical strength in the nealed and work-hardened conditions. None of t singly gave the answer. However, several gave ma advantages in some particular property. A combina of two chosen elements produced a triple alloy w turned out to give the results desired. In fact, its p erties are almost unbelievably good. This alloy has given the name Cond-Al, meaning conductor alumi It contains small fractional percentages of iron magnesium. This material has been used for rewin several old fields originally wound with soft alumi and one of these has been in service since Dece 1949. The use of this material is expected to contri significantly to the development of much larger rpm generators than have so far been ordered.

IMPROVED MAGNETIC MATERIALS

The rotors of large turbine generators are now al universally made of solid-steel forgings. Other ty such as those consisting of plates bolted togethe with laminations mounted on a through shaft, practically disappeared. The development of these forgings is quite a story in itself, the emphasis ha been on obtaining the required high mechanical stre in all parts and throughout very heavy sections. is done by (1) employing an alloy steel containing a 2.5 to 3.0 percent nickel and usually a fractional centage of molybdenum; often with some vanadium; (2) by giving the forging an elaborate heat treatm

In general, only the physical properties have included in the forging specifications. Neither the c ical constituents nor the magnetic properties been specified. By actual analysis, the chemistry these large shaft forgings has been remarkably unif among the several suppliers. The magnetic prope for the most part have also been quite good and rea ably uniform, although some exceptions have occu in the past. About ten years ago two generator f had to be replaced on account of excessive excita caused by poor magnetic properties. A long-term vestigation has been carried out since that time, the twin purposes of obtaining more consistent properties and of improving the average level as a as possible. The steel suppliers, and the Com's Works Laboratory and Research Laboratory co-operated in this investigation, which has essed rather slowly but surely in the right direc Some of the findings are that the carbon and nium content of the forgings should be kept to a mum, and that the heat treatment should be coned within certain limits. The results have been lent. No more cases of excessive excitation have rred, and the average magnetic properties have imed appreciably, without sacrifice of mechanical gth. This permits some increase in the magnetic ng of the electrical design, since it usually is the ation of the rotor steel which limits the amount of l flux corresponding to the rated voltage of the rator.



6. **Apparatus for compression testing of field coil conductor materials perating temperatures**

trasonic testing of the rotor forgings has been in ral use for three years, and has proved to be an exngly valuable means for detecting internal flaws.[19]

other recent development is the application of ted-grain strip steel to the stator cores of turbine rators. At first thought, this might seem a miscation, on account of the fact that the principal tion of the flux path in the teeth is at right angles at in the outer portion of the core. This outer por however, is quite massive in turbine generators, accounts for the major portion of the core loss. the cross-grain properties of good oriented-grain steel are comparable to the properties of the pre standard hot-rolled sheet steel, both in losses and citation requirements. Consequently, a major gain be made by arranging the grain in the circumtial direction to favor the larger loss in the outer on of the core, without prejudice to the tooth n. This arrangement was tried out on a 1250-kva generator in 1945 and thorough tests indicated a ed advantage. Since that time, oriented-grain strip steel has been applied to progressively larger generators, of which about a dozen have been tested and put into service.* Factory facilities have been provided for the higher-temperature annealing process required for realization of the improved magnetic properties, and the application of this new material is rapidly being extended to the largest sizes of turbine generators.

There are two ways to use this strip steel to advantage. Working it at previous magnetic densities brings about a handsome reduction in core loss, which has usually been the largest loss in hydrogen-cooled turbine generators. Or, by cutting down the radial depth of the outer part of the core, and working at higher magnetic densities, the weight and dimensions of the machine may be reduced appreciably.

The latter alternative is of especial importance in very large machines in which the weight and dimensions of the stator are such as to crowd shipping limitations. On order are very large generators, of both four-pole and two-pole design, that would require a double frame with separate shipment of the inner frame with core and coils assembled, and the outer frame in two or three pieces, except for the advent of the new oriented-grain steel which makes it possible for them to be designed with a single stator frame arranged for complete assembly and test in the factory and shipment in one piece. It is expected that the use of oriented-grain strip steel will become general in turbine generators in the near future.

INCREASINGLY LARGE 3600-RPM GENERATORS

The phenomenal growth in capacity of 3600-rpm generators in the past 20 years has not come about because of any inherent advantages over the well established 4-pole 1800-rpm machines. Actually, the higher-speed generators are somewhat bulkier, heavier, and less efficient, and are subject to quite a number of distinctive problems and limitations. The advantages of the 3600-rpm design are all to be found in the turbine end of the set, where the quest for ever higher thermal efficiency and over-all economy of power production has led to continual increases in steam temperatures and pressures. To meet these modern steam conditions, it has been found both technically and economically necessary to use the highest feasible speed of rotation, which permits minimum diameters of turbine shells and minimum numbers of stages. The production of increasingly large high-speed generators to go with these turbines has been an intensely interesting development.

In extending the rated capacity of 3600-rpm generators from about 12,500 kva in 1929 to over 125,000 kva in 1950 with much further progress in sight—a great many problems have had to be solved, some of which have been touched upon earlier in this article. Hydrogen cooling was a basic innovation; without it and the other

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*The initial developmental work of applying grain-oriented strip to turbine generators, including building and testing these first generators, has been carried out by the Thomson Laboratory and the Generator Engineering Division at Lynn (Mass.). The details of this development are described in a technical paper submitted to the AIEE in January 1951, entitled "The Use of Preferred Orientation Strip Steel in Turbine Generator Stators," by J. W. Apperson, Thomson Laboratory, and C. B. Fontaine, Generator Engineering Division, Lynn.

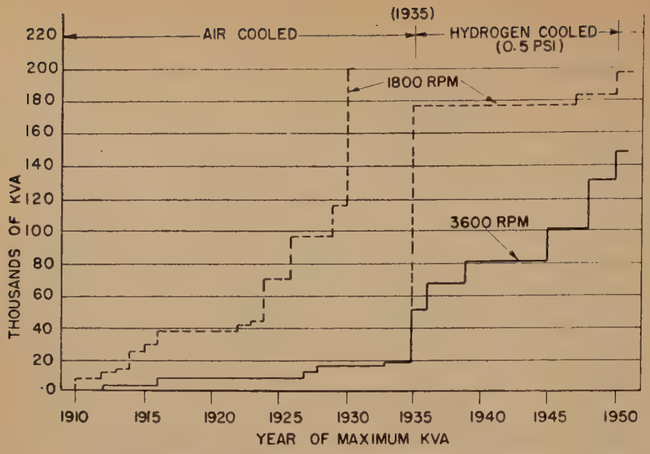

Fig. 7. Chart showing increase in rating of 3600- and 1800-rpm turbine generators since 1910

improvements in ventilation, modern generators of large output would hardly be feasible. Various mechanical improvements, particularly the means for eliminating double-frequency vibration, have also been a practical necessity. Other basic improvements have been made in field-coil materials which resist thermal distortion, and in the magnetic materials of both rotor and stator, as well as in insulations. All of these are essential for the large machines now being built, and the larger ones to come. However, the old and long-familiar limitations of dimensions are still present: namely, the limitation of rotor diameter by centrifugal stresses, of rotor length by vibrational considerations (critical speed), of stator diameter by shipping clearances, and of weight of stator by railroad-car capacity. Means have been found in many ways to overcome these limitations somewhat, or to increase generator capacity in spite of them.

Rotor diameters for 3600-rpm generators have been increased greatly by taking advantage of increased strength and uniformity of forgings and of improved field-coil conductor materials and insulation—keep within established safe limits for the principal stre in the bore hole and tooth roots, and particularly in crushing pressure of the coils on the insulation and the hoop stresses in the retaining rings or cylindr caps which carry the end portions of the field c The retaining rings are a major limitation, as in a m ern large machine using alloy steel rings the h stress may be 65 to 75 percent due to the weight of rings themselves and only 25 to 35 percent due to useful coil load they carry. In such a case, a surprisin small increase in diameter would require the coil l to be reduced to zero, as the limiting stress would reached in the component due to the ring itself. In t connection, a major gain is made possible by the dev opment of Cond-Al, which is the aluminum alloy p viously referred to and which has both good electri conductivity and excellent mechanical strength, creep resistance.

Rotor lengths have also increased greatly, even relation to the larger diameters now found possib and this has come about by a whole series of devel ments, including ventilation, conductor materials, research on vibration and balancing technique. haustive studies have been made on the critical, more properly resonance, speeds of generator sha including observations on many machines in servi tests on dozens of scale setups, and the developm of improved analytical methods. As a result, a m better understanding has been obtained of the vib tional characteristics of long high-speed rotors, a techniques have been developed to insure that th can be well balanced and will run smoothly—ev better than the standards of operation which w acceptable on the smaller machines of the past.

The diameter and weight limitations on the sta are fixed by shipping clearances and weight limits. the 1920's, these were overcome, in the case of ve

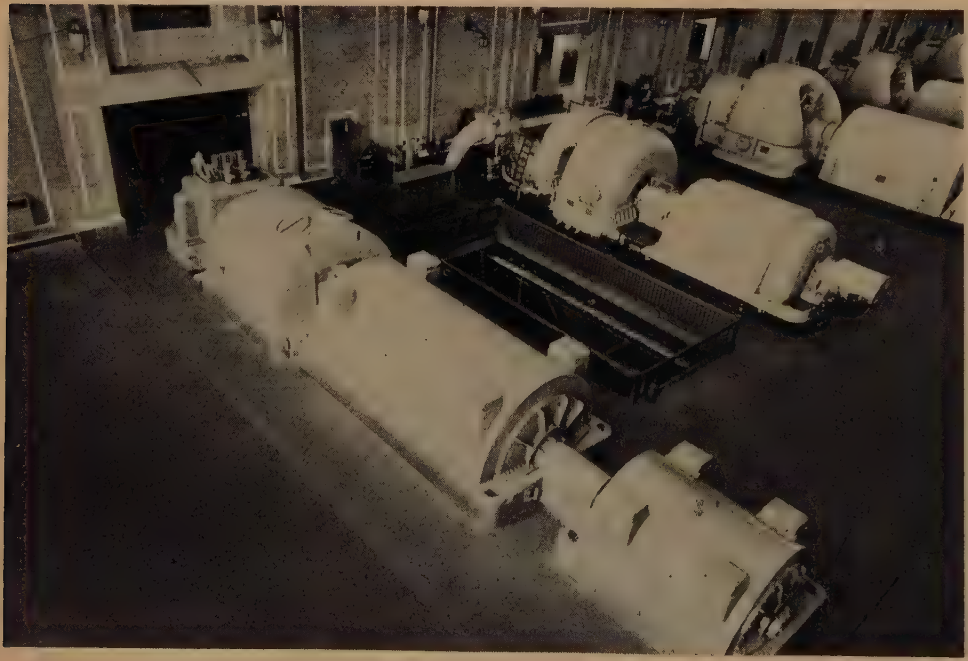

Fig. 8. Turbine generator rated 111,765 kva, 3600-rpm, 15 psig hydrogen pressure, in service since December, 1947

e 1500 and 1800-rpm air-cooled generators, by ble-frame designs; the inner frame, carrying the and coils, being shipped in one piece, while the er frame was subdivided for shipment. This double- ne construction we have not so far found neces- for generators designed for hydrogen cooling—even o 183,333 kva 1800 rpm—although it may be used for very large machines. Its use has been contem- ed recently, but has been postponed by the in- luction of oriented-grain strip steel for the stator , as mentioned previously.

IG. 7 shows the increase in the basic kva rating of)-rpm generators, both air-cooled and hydrogen- ed, over the years since 1910. For comparison, a are also included on 1800-rpm generators. The scale shows the year in which these machines e ordered; and the rating scale indicates the name- e kva rating, which in the case of hydrogen-cooled hines is based on 0.5 psi hydrogen pressure. Starting ut 1939, advantage was taken of the improved cool- effect obtained by increasing hydrogen pressure to si gage, for which a 15 percent increase in capacity obtained. And in 1945 a further increase was re- nized for pressures up to 25 or 30 psi. This subject of eased capacity of hydrogen-cooled generators as a tion of gas pressure has been previously presented.(20) ill be observed that a tremendous jump in the ca- ity of 3600-rpm generators took place in 1935 and 6, with the advent of high-pressure high-temperature bines, and hydrogen cooling for the generators. The est air-cooled generator for 3600-rpm was a 50,000- machine ordered in 1936. In the past five years ther series of large steps has been taken, and the is not nearly in sight, as design studies and even ative quotations have been made on 3600-rpm hines of 180,000-kva base rating.

he first 100,000-kva 3600-rpm generator, which is wn in FIG. 7 as ordered in 1945, actually went into service in December 1947, at the Essex Station of the Public Service Electric and Gas Co. of New Jersey, near Newark. A photograph of this machine is shown in FIG. 8. This machine was actually given a special nameplate rating at 15-psi gas pressure (111,765 kva, 0.85 pf, 95,000 kw, 13,000 volts with a special short-circuit ratio) which is equivalent to the 100,000-kva 0.8-pf standard rating at 0.5 psi, and the same design has been used for this rating. The operation of this machine has been eminently satisfactory, as it runs smoothly and both armature and field windings are remarkably cool.

That pioneer 100,000-kva 3600-rpm machine has been followed by many others of the same or equivalent rating, and 9 of them are now in service, with 12 more on order. FIG. 9 shows a longitudinal section through this machine. A similar generator of somewhat greater length was designed for 112,500 kva and orders have been received for nine of these machines. The first of these was for the new Yates Station of the Georgia Power Co., near Newnan (Ga.) and went into service in September 1950. Its rating is 111,111 kva, 100,000 kw, 0.9 pf. The others of this size are in process of manufacture, shipment, or erection. In 1948 a still larger generator of similar design was ordered by the Public Service Company of Northern Illinois for its Waukegan Station, being rated 129,412 kva, 110,000 kw, 0.85 pf. This machine is now nearing completion in the factory and is expected to be installed in 1951. Six others of equivalent rating are on order.

All of those machines rated 100,000 kva and above have been designed with one-piece stator construction, and have been or will be completely assembled and tested at the factory. The dimensions and weight of the finished stators have been such as to tax the limitations of railway shipment facilities, and there are spots in this country where great difficulty would be encountered in delivering so large a machine. The COVER

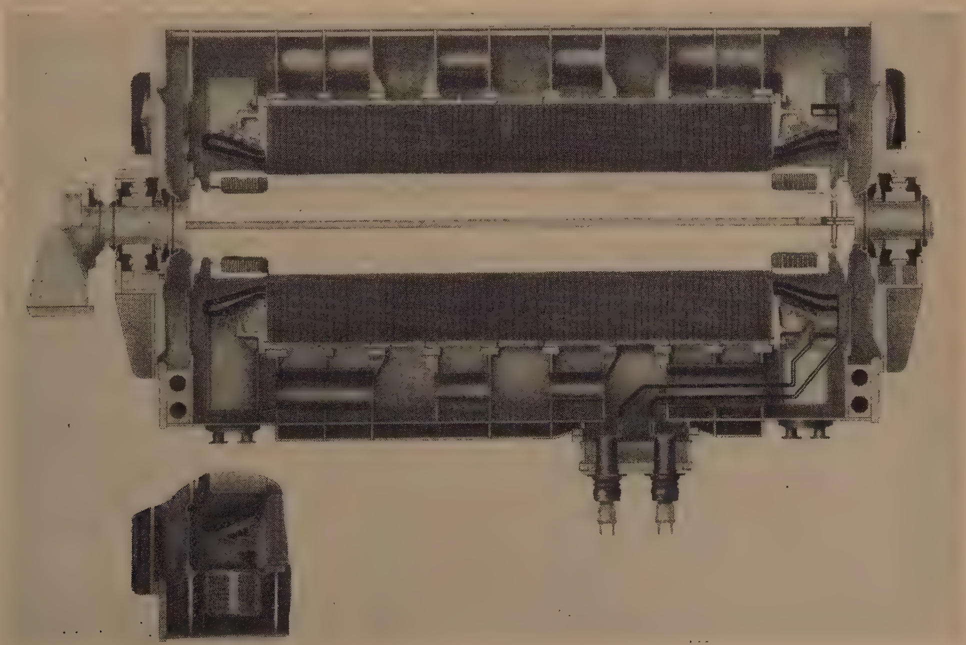

Fig. 9. Longitudinal section of 111,765-kva generator shown in Fig. 8

shows one of these machines being hauled over the highway at the end of its transcontinental train trip for installation near San Francisco in Station "P" of the Pacific Gas and Electric Company.

The largest 3600-rpm generator on order as of October 1, 1950 has a 147,000-kva, 125,000 kw, 0.85-pf rating and is for the Philadelphia Electric Co., the order for which was placed in the spring of 1950. At the time this machine was quoted, the preliminary design was based on double-frame construction with shipment to be made disassembled. However, further design studies, capitalizing the advantages of oriented-grain strip steel, have resulted in the abandonment of the double-frame feature for this machine, as it has been found possible to build it closely within the weight and dimensional limits of the Waukegan generator. Another feature of this Philadelphia machine is of special interest: its output is to be transmitted at the generator voltage of 13,800 volts. So large a kva rating at this voltage runs the current capacity up to an unprecedentedly high value, 6150 amp per phase at base rating. In view of the inherent limitation of armature windings for two-pole generators to not more than two parallel circuits per phase, and in view of the fact that delta-connected armature windings have been generally unacceptable, the current to be carried by each coil is required to be 3075 amp at nameplate rating, and proportionately more with increased hydrogen pressure. This is about 20 percent above past experience. An armature coil for such heavy current must be of distinctly special design. It necessarily requires wide, deep slots in the stator core, so wide that the conventional 2-wire wide Roebel transposition bar is not practical on account of the extreme width of the conductors, particularly as the depth required is so great as to require unusually fine stranding of the conductors. A practical solution has been found by employing a special 4-wire wide Roebel transposed bar. This bar is unusually heavy, and may prove to be rather expensive, but should be entirely practical. The two parallel circuits of the armature winding are brought out through separate sets of bushings at opposite ends of the stator, and are to be permanently paralleled externally.

For optimum generator design as well as for best economy for handling the output current in the power station, it seems that generator voltages for 3600-rpm machines larger than 112,500 kva should be increased above the long-established standard voltage, 13,800 volts. (Also there are advantages in raising the excitation voltage from 250 to 375 volts.) The actual armature voltage to be chosen is subject to some adjustment, but in general should be higher as the kva rating is increased. In case of special requirements as at Philadelphia, special designs can be developed; but it is felt that, in general, over-all economy can best be served by employing higher voltages up to as high as 20 or 22 kv for the largest ratings. In this connection it might be well to point out that 8 large generators in the Chicago area have been in service for about years running at 22 kv, and have given a good accou for themselves. In view of this experience and the c siderable advance in insulation practices since th machines were built, there should be no doubt abo the reliability of generators designed for the high voltages suggested.

There is much more progress to be made in futu years in the development of large high-speed gene tors, and many projects for improvements yet to realized have been under way for years. Not only w still larger machines be built, as they are found to economically and technically feasible, but the prese high levels of general quality, reliability, and smoot ness of operation in all sizes will be raised even high

ACKNOWLEDGMENT

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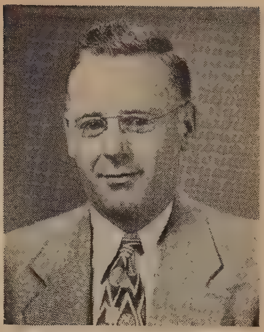
LECTROLYTIC CORROSION OF METALS

This is a factor that the designer must not overlook when selecting materials. The electromotive series provides a guide in choosing materials that will not give rise to electrolytic corrosion, but it must be supplemented by knowledge of what conditions may introduce exceptions



Arthur E. Durkin

By A. E. DURKIN
Thomson Laboratory, General Electric Company
West Lynn, Mass.

HEN designing new equipment, important consideration should be given to the selection of such erials that the part will operate in service without ng adversely affected by ordinary corrosive atspheres.

f dissimilar metals are used in the design, and the t is operated in or even subjected to the atmosphere, re is a possibility that localized pitting and corrosion result. This condition is known as electrolytic rosion and is governed largely by the positions of materials in what is called the Electromotive es. This series lists the order in which elements and als can replace others from solution. When any dissimilar metals in this series are in contact in a able electrolyte, a cell is set up in which the metal t is higher in the series is the negative pole and the er one the positive pole. The farther apart the als are in the series, the greater the potential erence between them and the higher the corrosion .

he higher, or more anodic, metals in the series are resistant to corrosion than the lower or cathodic als. Therefore, accelerated action takes place at former, while decreased activity takes place at latter. The anode may be defined as the negative in a battery or the positive electrode of a solution n electrolyte through which current is being forced, t may be described as the electrode at which an lation process takes place. While each metal dises from solution those that are below it in the es, the metals' position in the series is not always olute because ion concentration modifies the effecpotential between two metals in contact with the tion. There is, however, little likelihood that two als far apart in the series will reverse potentials, this may take place between two metals close ther.

n example of localized electrolytic corrosion is trated in Fig. 1. At the right is shown the shaft a six-stage boiler-feed pump after three months of ation. It will be seen that the outboard end (area s badly pitted. On this end, a series of graphiteregnated pump packings was in contact under sure with the 440 type stainless-steel shaft. When the packing failed during operation, the shaft was removed and the pitted condition was revealed. The inboard end (area *A* plus *B*) showed no corrosion *when the shaft was removed* as no packings had been in contact with those areas.

To duplicate the corrosion in the Laboratory, a packing ring was placed on the area *A*, and the area *C* was masked with a suitable stop-off paint to prevent its being further pitted while the shaft was being subjected to a 316-hr salt-spray test. Area *B* was exposed during the test. As will be seen, corrosion took place in area *A* but none in area *B* (where no packing was in contact with the shaft). It may be noted that while the corrosion in the Laboratory test is more severe, it is, nevertheless, similar in nature to that which resulted in service operation. If the pitting of future shafts is to be eliminated, a different type of packing must be used in the assembly. The reasons for this substitution will become evident later.

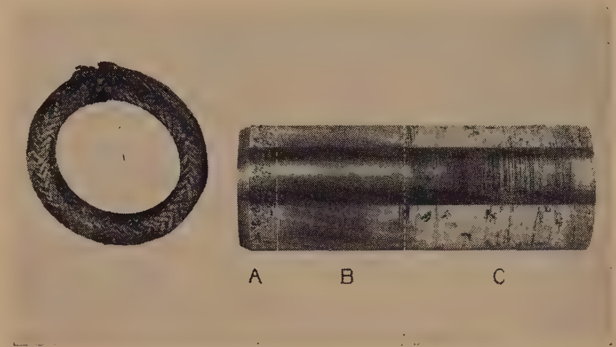


Fig. 1. A graphite-impregnated packing ring and an example of electrolytic corrosion of a steel shaft resulting from contact with such rings over the areas *A* and *C*

A more severe example of electrolytic corrosion is illustrated in Fig. 2. This shows two views of two magnesium parts after less than 100 hr in a 20 percent salt-spray test. The part at the left was dichromate treated with Dow No. 7, was primed and finished with organic topcoats, and the cadmium-plated hardware was attached prior to testing. The part on the right was unprotected other than by the dichromate treatment. While the two parts were subjected to the same test conditions simultaneously, it will be noted that the cadmium-plated hardware has fallen off completely in several areas on the right-hand part while the same

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s article is so paged that, without mutilating other articles, it can be y removed for filing as a group of full-size consecutive pages.—Editor

TABLE I

THE ELECTROMOTIVE SERIES

ANODIC END

- Lithium (−2.959 v)
- Rubidium
- Potassium (−2.92 v)
- Strontium
- Barium
- Calcium (−2.7 v)
- Sodium (−2.71 v)
- Magnesium and its Alloys (−1.55 v)
- Aluminum (−1.33 v)
- Beryllium
- Uranium
- Manganese
- Tellurium
- Zinc (−0.76 v)
- Chromium (−0.56 v)
- Sulfur
- Gallium
- Iron (Fe^{++}) (−0.44 v)
  - Galvanized Steel (1)
  - Galvanized Wrought Iron
  - Al-Zn-Mg Alloys (eg: Al-75S) (2)(3)
  - Al-High Mg. Alloys (eg: Al-220)
- (A)Al-Low Mg. Alloys (eg: Al-4S)
  - Aluminum plus very low percentage of alloying Constituents (eg: Al-53S)
  - Alclads
- Cadmium (−0.40 v)
- Al-Si-Mg Alloys (eg: Al-356)
- Al-Cu Alloys (with or without small additions of Mg) (eg: Al-24S)
- Al-Cu Alloys (with or without small additions of Zn) (eg: Al-113)
- Al-Cu-Si Alloys (eg: Al-108)
- Mild Steel
- Copper Steel
- S.A.E. 4140
- S.A.E. 3140
- Wrought Iron
- Cast Iron
- 4–6% Chromium Steel, Type 501 or 502 (4) (Active)
- 12–14% Chromium Steel, Types 403, 410, 416 (Active)
- 16–18% Chromium Steel, Type 440 (Active)
- 23–30% Chromium Steel, Type 446 (Active)
- Indium (5)
- Thallium
- Cobalt (−0.28 v)
- Ni-Resist Cast Iron
- 50–50 Lead Tin Solder
- 17% Cr-7% Ni Steel, Type 301 (Active)
- 18% Cr-8% Ni Steel, Types 302, 303, 304, 321, 347 (Active)
- 23% Cr-14% Ni Steel, Type 309 (Active)
- 25% Cr-20% Ni Steel, Type 310 (Active)
- 18% Cr-12% Ni-3% Mo Steel, Type 316 (Active)
- Hastelloy "C" (59% Ni, 17% Mo, 5% Fe, 14.6 Cr, 5% W, 0.1% C)
- Lead (−0.12 v)
- Tin
- Iron (Fe^{+++})
- Hydrogen (0.00 v)
- Antimony
- Bismuth
- Arsenic
  - Muntz Metal (60% Cu, 40% Zn) (6)
  - Manganese Bronze (66.5% Cu, 19% Zn, 6% Al, 4% Mn)
  - Naval Brass (Add. of ¾% Sn to Muntz Metal)
  - Nickel (Active)
  - 60% Ni-15% Cr (Active)
  - Inconel (78% Ni, 13.5% Cr, 6% Fe) (Active)
- (B)80% Ni-20% Cr (Active)
  - Hastelloy "A" (60% Ni, 20% Ni, 20% Mo, 20% Fe, 0.1% C
  - Hastelloy "B" (65% Ni, 30% Mo, 5% Fe, 0.1% C)
  - Yellow Brass (58–70% Cu, 0.50–1.5% Sn, 0.75–3.5% Pb, Balance Zn)
  - Admiralty Brass (71% Cu, 28% Zn, 1% Sn)
  - Aluminum Bronze (Add. of 2¼% Al to 75% Cu-25% Zn Allo
  - Red Brass (85% Cu, 15% Zn)
- Copper (-ic) (+0.522 v)
- Oxygen
- Polonium (+0.34 v)
- Copper (-ous) (+0.52 v)
- Iodine
- Tellurium (Te^{++++})
  - Silicon Bronze (1.0 to 3.0% Si) (7)
  - Nickel-Silver
  - Ambrac (5.0% Zn, 20% Ni, Balance Cu)
  - 70% Cu-30% Ni
  - Comp. G-Bronze (88% Cu, 2% Zn, 10% Sn)
  - Comp. M-Bronze (88% Cu, 3% Zn, 6.5% Sn, 1.5% Pb)
  - Silver Solder
  - Nickel (Passive)
  - 60% Ni-15% Cr (Passive)
  - Inconel (Passive)
  - 80% Ni-20% Cr (Passive)
- (C)Titanium
  - Monel (70% Ni, 30% Cu)
  - 12–14% Cr Steel, Types 403, 410, 416 (Passive)
  - 16–18% Cr Steel, Type 440 (Passive)
  - 17% Cr-7% Ni Steel Type 301 (Passive)
  - 18% Cr-8% Ni Steel, Types 302, 303, 304, 321, 347 (Passive)
  - 23% Cr-14% Ni Steel, Type 309 (Passive)
  - 23-30% Chromium Steel, Type 446 (Passive)
  - 25% Cr-20% Ni Steel, Type 310 (Passive)
  - 18% Cr-12% Ni-3% Mo Steel, Type 316 (Passive)
- Mercury (+0.85 v)
- Silver (+0.80)
- Lead (Pb^{++++})
- Palladium
- Bromine
- Chlorine (+1.36 v)
- Graphite (8)
- Gold (-ic) (+1.3 v)
- Gold (-ous)
- Platinum
- Fluorine

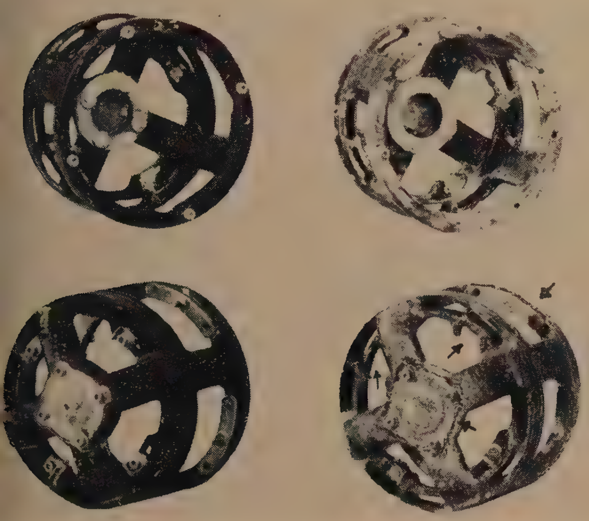
CATHODIC END

NOTES

(1) Members of Group (A) are listed relative to each other, but the position of the group with respect to the group between chromium and ferrous iron is u certain. The group, however, is listed correctly between zinc and cadmium.
(2) Aluminum types are the standard designations of the Aluminum Co. of America.
(3) The heat treatment of aluminum and its alloys has an effect upon their galvanic potentials. They fall in the aluminum group, however, regardless of t heat treatment.
(4) Stainless Steel types are standard American Iron and Steel Institute designations.
(5) Indium, thallium, and cobalt are listed relative to each other, but their position relative to the stainless steels is uncertain. They are properly placed b tween aluminum and lead.
(6) The members of Group (B) are listed relative to each other, but the position of the group relative to ferric iron to arsenic is uncertain. The group is, ho ever, properly placed between tin and copper.
(7) The members of Group (C) are listed relative to each other, but the position of this group with respect to iodine, tellurium, and mercury is uncertai However, the group is properly placed between copper and silver.
(8) Graphite lies between lead and gold but its position relative to palladium, bromine, and chlorine is uncertain.

as on the left-hand part are relatively unaffected. e arrows show the pits as well as the areas to which hardware was attached prior to the test. As is wn, the insulating paint films on the part at the has prevented electrolytic action, while the right-d part has disintegrated.

The tendency of a metal to corrode can be measured calculated by the potential at any time between the tal and its ions in solutions. The value of the poten-l is measured against a standard electrode, such as hydrogen electrode. The values obtained depend, refore, upon the metal itself and the solution in which



g. 2. Another example of localized electrolytic corrosion, this of agnesium parts with cadmium-plated hardware when subjected to salt-ray tests. At the left: two views of a part that had been amply protected ainst corrosion: at the right, two views of a duplicate part that had not en sufficiently protected.

s measured. By making the potential measurements he metal in a solution of its own salts which contains andard concentration of the metal ions, the metal's ition in the electromotive series is determined.

he Electromotive Series shown in Table I was piled to include the common types of alloys as l as the metals from which engineering groups must ct materials for the design and manufacture of their ducts. This table is not absolute, as has been men-ed, but it is a guide in determining how safely metals can be used in contact with each other.

djacent to some metals are their potentials. No empt has been made to complete the potentials of the metals and elements shown. The few shown are reference purposes only. Hydrogen as shown is the rence point. In interpreting the table, it is necessary have an understanding of some of the conditions ch may modify the action of a metal.

eference is now made to active and passive metals he table. A passive metal is one on which a thin film ns and prevents the metal from dissolving in its ironment. These thin adherent films depress the ential and make the metal more noble. A noble al is one which shows little tendency to combine other substances. An example of a noble metal is gold. One definition of passivity, according to H. H. Uhlig, is: "A metal active in the Electromotive Series, or an alloy composed of such metals is considered passive when its electrochemical behavior becomes that of an appreciably less active or noble metal."

Passivity is usually produced by the metal's being in contact with oxidizing agents. Its passivity may be lost if it then comes in contact with a reducing solution, or it may be passive if it is the anode in a cell of high current density. Passivity may be retained by a metal even after the metal is removed from the passivating medium. However, the passivity is lost in time and the metal reverts to its original state. The position of a passive metal in the series is so changed that it is cathodic to a piece of the same metal which is in an active condition.

Surface conditions such as oxides, gas films, or other passive films often cause deviations from standard potentials. For example, the resistance of attack of pure aluminum is due to the formation of a closely adhering impervious layer of oxide which slows, and finally stops, further oxidation. The method of surface treatment of metals has a pronounced effect upon the potential. Electropolished steel is anodic to emery-abraded steel, which is anodic in turn to sandblasted steel. Similar differences have been noticed for nickel.

Some metals in the series are listed as being both active and passive, depending upon the conditions. If in doubt as to whether an active-passive metal will be active or passive, assume that it will be active if its area is relatively small in respect to the other metal, and passive if its area is large.

An important consideration in making corrosion predictions is the relative areas of the anodic and cathodic metals. In solutions in which the potential of the cathode changes (polarizes) as a result of current flow, but the anode does not polarize, the current flow is proportional to the relative cathodic area. If the area of the cathode is reduced by half, the total galvanic corrosion of the anode will be reduced by half. If the area of the anode is either doubled or reduced by half, the galvanic weight loss of the anode will remain unchanged, but the intensity of the attack will increase with decreasing anodic area. If the anode polarizes but not the cathode, the reverse holds true. The noble metal should have a smaller area than the anodic metal because the latter is subject to attack.

Electrolytic corrosion usually occurs as localized attack near the areas of contact and may result in rapid failure though little corrosion is found elsewhere. The use of a combination of metals close together in the series will minimize the danger of electrolytic corrosion. Cathodic protection involving an impressed potential and similar potential methods of minimizing corrosion can be successful only if the electromotive series is properly interpreted. Insulation of the metals from each other at areas of contact is also successful in preventing electrolytic corrosion. For such insulat-

(Concluded on following page)

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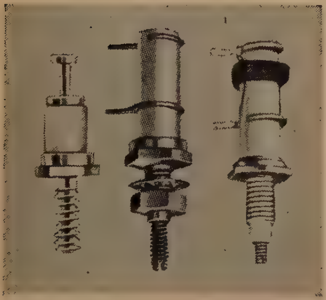

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ELECTROLYTIC CORROSION OF METALS

(Continued from preceding pag

ing purposes, proper surface treatment plus a suitab coat of paint or heavy caulking compound or a suitab gasket material should be used.

The writer wishes to express his appreciation t Carroll Seversike of the Chemical and Metallurgica Program for his assistance in preparing this article.

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HIGH LIGHTS AND SIDE LIGHTS

Anaerobic Permafil

A material has been developed which
nains liquid as long as a stream of air
bbles through it, but which hardens
a few minutes when away from air.
properties are opposite to those of paint,
ich hardens when exposed to air.

Since this new material is able to pene-
te extremely small cracks before hard-
ng, a possible application is a tight
l for stopping nearly invisible leaks, or a
ipe dope" for sealing threaded unions.

Called "anaerobic permafil," the sub-
nce is the latest in a series of related
npounds which originally were called
lventless varnishes." Ordinary var-
hes contain some solid resin dissolved
a liquid solvent. When applied to a
face the solvent evaporates and the
nish remains as a hard layer. Anaerobic
rmafil remains liquid as long as it is
rated. When away from air it solidifies
ickly, without heating or addition of
alysts and accelerators.

When two metal strips are coated lightly
h it and clamped together, the joint
l support ten pounds after ten minutes.
er 20 hours, it will hold 100 lb. If still
ter hardening is desired, the permafil
y be heated, up to 212 F; solidification
n takes place in a minute or less.

One proposed use of anaerobic permafil
in eliminating the lock nut needed to
ld another nut tightly on a bolt. A few
ops placed on the threads of the bolt
t before the nut is screwed on harden
tightly that very considerable force is
uired to remove the nut. Another use is
sealing against leaks. The permafil may
applied to threaded joints in pipes,
ere the liquid penetrates into the
vices and then hardens. Also, if painted
porous castings, it enters the pores and
ders the casting airtight.

Anaerobic permafil is still the subject
experimental investigation. It is not yet
ilable commercially.

Anaerobic permafil, which hardens when kept away from air, is applied here to the threads of a bolt for demonstration

Portable Concrete Plant

One of the few portable aggregate and batch plants in the United States is being operated at Newman (Cal.) The plant has a capacity of 245 tons of specification aggregate per hour, and is so designed and constructed that it can be disassembled and moved to new job locations.

Originally built to supply highway paving aggregate, the plant was moved to Westly (Cal.) in 1946 to produce aggregate for the Delta-Mendota Canal. It was then moved to its present site near Newman, a distance of about 20 miles, where it was assembled and in operation in ten days.

This aggregate and batch plant can be disassembled and moved to new job locations

The batch plant has supplied aggregate for over 45 miles of the Delta-Mendota Canal which, when completed, will supply the San Joaquin Valley with additional water for irrigation.

The motors on this installation range from 7½-hp speed reducers which drive the conveyor belts at various stages of the process, to a 150-hp motor which operates a rock crusher at the beginning of the conveyor system. In addition to the motors that drive the conveyors and other machinery, a 75-hp vertical motor operates a deep-well pump supplying the plant with water.

When operations at Newman have been completed, the plant is scheduled to be disassembled and shipped to Yuma (Ariz.), where it will be reassembled to produce aggregate for the new Welton-Mohawk Canal.

Ten Turbine-electrics

The first order has been placed for gas turbine-electric locomotives—the newest form of rail motive power. Similar to the 4500-hp unit that has been undergoing test on regular freight runs for the last year and a half, the ten compact and powerful new locomotives will be assigned to freight service and will permit fuller evaluation of their potentialities under a wider variety of operating conditions.

Largest Self-unloader Bulk Carrier

Propulsion and conveyor equipment is being built for the largest self-unloader ore carrier on the Great Lakes.

Designed to unload 5000 tons of limestone an hour, the conveyor system will utilize two 200-hp hold conveyor motors, two 200-hp elevator motors, and two 250-hp boom conveyor motors. The unloading thus achieved will be greater than on any other self-unloader now in service.

The propulsion equipment will include one 7000-hp cross-compound, double-reduction turbine-gear set. The design steam conditions will be 450 psig, 750 F, with exhaust to 28.5 in Hg vacuum. In port, two 600-kw turbine-generator ship's service sets will power the conveyor system.

The new ship will be completed for regular service for the season of 1952.

NEW PRODUCTS: AND WHAT THEIR MAKERS HAVE TO SAY ABOUT THEM

Scale Thickness Indicator

A boiler tube scale thickness indicator for measuring the thickness of scale or other deposits on the inside of boiler tubes, water-wall tubes, or other straight or bent tubes or ducts of circular cross section. The instrument works on the magnetic-induction principle and is independent of the material composition of the deposit. It determines the results of feed-water treatment without uncertainties and long delays. Steel tape extends the electro-magnetic probe head down the boiler or water-wall tube from the upper header or drum by one person while another records the scale thickness for each foot of travel.—*Haskins Turner Co., 1617 Third St., Jackson, Michigan.*

Multiple Unit Signal

The Panalarm back-lighted multiple unit signal for use as a trouble signal in process industries and power plants to detect off-normal operation of almost any type of equipment. The hermetically sealed signal combines signal lights and relay to form a single unit that plugs into a universal chassis, making it easy both to install and service. A simple but effective lock-in arrangement consists of a locking stud which fastens to the chassis and extends through a hole in the signal unit; a thumbnut screws over the end of the stud, holding the unit tightly in place. Designation plates for each signal are printed to identify each process or piece of equipment and the condition existing when the alarm sounds.—*Panalarm Products Co., 7218 No. Clark St., Chicago 26, Ill.*

Resistor

A boro-carbofilm resistor to fill the need for an increased range of resistance as well as a lower temperature coefficient. It possesses stability and has a low noise level. With their slow aging and low temperature coefficient of 20 parts per million per deg C, the resistors are advantageous for high-frequency communications and electronic applications. They are offered in ¼-, ⅓-, ½-, 1-, and 2-watt sizes.—*Wilkor Products, Inc., 2882 Detroit Ave., Cleveland 13, Ohio.*

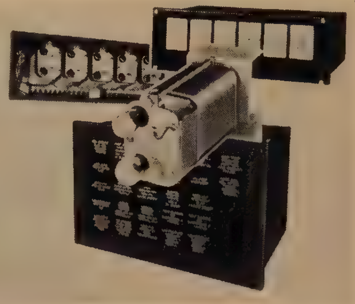
Base and Sockets

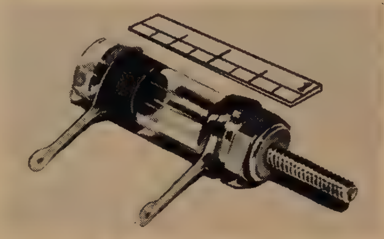
The Alden "20" noninterchangeable base and sockets, an addition to their line of plug-in components. Its scope for mounting electronic components includes open and shielded units, relays, filters, terminal cards for wiring complete assemblies, etc. Design of the base eliminates many of the difficulties encountered with conventional type bases. There is no molded center boss to break; pins are strong and stubby, do not bend or break out; and by selecting variations of pin layout of less than 20 pins, critical voltages and frequencies can be isolated and the base made noninterchangeable, permitting it to mate only with correct socket.—*Alden Products Co., 117 N. Main St., Brockton, Mass.*

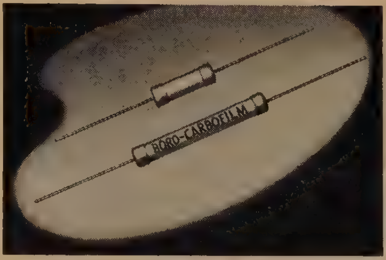
Press

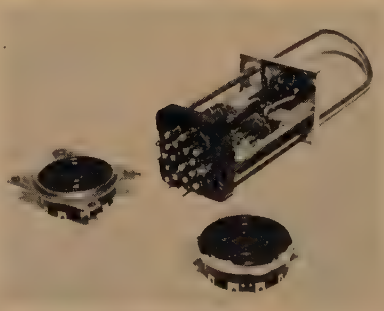
A 40-ton cam-operated S-5 powder-metal press for the production of electric motor, radio, and television parts; machine parts; cemented carbides; porous bearings; and other powder-metal pieces. A single hand-

Scale Thickness Indicator


Multiple Unit Signal


Variable Capacitors


Resistor


Base and Sockets

Pollution Test Unit

wheel adjustment sets the machine for t proper compression level of the lower punc automatically taking care of the ejecti level by this single setting. The plunge spring pulldown is low, eliminating an tendency for the lower punch to hang in t die. The main lower plunger is provided wi a guide pin and bracket to prevent it fro twisting under compression. The upp punch assembly has been modified to si plify set-up. To afford more perfect alig ment a clamp ring is used instead of a loc nut. This modification has been so design that punches and dies are interchangeab with former models. The press can be us for sizing or coining, as well as for formi through the use of a special attachme —*F. J. Stokes Machine Co., 5900 Tab Road, Philadelphia 20, Pa.*

Variable Capacitors

Piston-type 1-in. long variable trimme capacitors provide the minimum capaciti needed for accurate and stable electron adjustments. Smooth, precise settings with out backlash or disturbance from sever vibrations are made and maintained. C tubular design, they deliver continuall uniform change in capacitance in relation t rotation. Features include: approximatel zero temperature coefficient; "Q" rating over 1000 at 1 mc; 55 to 100 C operatin temperature; 10,000 megohms insulatio resistance; single-unit movable electrod and a special alloy adjustment screw.—*JF Manufacturing Co., Inc., 6101-6123 Sixteen Ave., Brooklyn 4, N. Y.*

Demagnetizer

An improved design of demagnetizin coil, highly effective in demagnetizing ma terials and stabilizing magnetic flux. An unshielded magnetically soft material, in cluding forms of iron and steel, can be de magnetized by this instrument. It can als be used to eliminate undesirable magneti flux from tools, drills, punches, small arms and any machined parts. The instrumen consists of an air-core coil built in a fram which can be mounted on table or bench The coil is rated 115 volts, 60 cycles, an is equipped with switch, pilot lamp, and flexible lead fitted with standard plug. Th rectangular opening 4½ by 8½ in. accom modates stock up to 8 in. wide.—*Specia Products Division, General Electric Co. Schenectady 5, N. Y.*

Pollution Test Unit

A simple and inexpensive activated-carbon gas-and-vapor adsorber for determining atmospheric pollution. The collecting device consists essentially of dual perforated activated-carbon-filled canisters assembled integrally with a motor-driven ai blower. It is so designed that 40 cfm o contaminated air can be drawn through a continuous uniformly dense 0.7 in. thick layer of 6–14 mesh granular activated carbon at a linear velocity of 25 fpm. By operating in a contaminated atmosphere for a given time, the volume of air that has passed through the carbon is known. Likewise, the adsorbable impurities entrained in that air will be collected by the carbon. Cannisters are then separated, sealed, and returned to laboratory for reactivation.—*W. B. Connor Engineering Corp., Shelte Rock Lane, Danbury, Conn.*

TRADE LITERATURE

OMATIC CONTROLS—Briefly outlines s and applications of automatic con- in heating, ventilating, and air-con- ning systems for the architect and neer who specify, the contractor who lls, and the owner who ultimately buys equipment. Cartoon-like sketches high- the text. Titled "The Control Story." nty-four pages.—*Barber Colman Co., ford, Illinois.*

RTS AND SCALES—A handsomely de- ed educational brochure containing a plete fund of information relative to neer's glass custom-made charts, stand- charts, scales and rules, staging fixtures, accessories for use on all makes of cal comparators, measuring, and micro ectors. Offered only to executives fur- ng their official title, together with the e of the government agency or firm h they represent. Forty-eight pages. log No. 9—*Engineers' Specialties Div., versal Engraving & Colorplate Co., Inc., Ellicott St., Buffalo 9, New York.*

OME PLATING—A simplified method of strial chrome plating is explained. De- es the Chromaster plating unit together Chromasol plate. Four pages.—*Ward ard Electric Co., Mt. Vernon, New York.*

L CHUCK—A neatly designed descrip- folder on the keyless self-gripping drill k manufactured by Leo Hjort Co., enhagen, Denmark. Four pages.—*ser Machine Tool Corp., 30 Park Ave., hasset, New York* (U.S. representative Hjort).

RUMENTS—A condensed catalog de- bing a selection of typical indicators, rollers, and combustion safeguards. An mpanying four-page price list contains listing, description, and current price ying to most of the standard instru- ts. Four pages. Bulletin Z-6600.—*elco Instruments Co., Chicago 7, Illinois.*

RUMENT TRANSFORMERS—A manual ring the theory of operation and the ication of instrument transformers. It written for practicing engineers and ents engaged in the fields of power ration, transmission, and application re metering and relaying problems can solved by the correct application of ument transformers. It covers basic amentals such as accuracy standards, lation, and polarity, as well as informa- on potential and current transformers. e $1.00. Seventy-six pages. GET-97A.—*aratus Department, General Electric pany, Schenectady 5, New York.*

INATED PLASTICS—An attractive pre- ation of a wide line of laminated and led plastics products outlining also company's production facilities and ics engineering services. Four pages. ed "Insurok Laminated and Molded tics."—*Richardson Co., 2762 Lake St., ose Park, Illinois.*

KNUTS—"Types of Locknuts and Their ciples of Operation" titles a graphically trated booklet covering the develop- cal phases of locknuts with emphasis on modern fasteners and locking methods ired by today's products. Twenty pages. *cknut Section, Industrial Fasteners tute, 3648 Euclid Ave., Cleveland, Ohio.*

LUMINAIRES—Two bulletins on Magna-Lite luminaires covering data on average reflectance; average efficiency; sizes, type, and number of lamps; and general information. The Dreadnaught Series of 2-lamp semidirect slimline luminaires, four pages, Bulletin DR-2; the general diffuse fluorescent luminaires, six pages, Bulletin AL-A-2-4.—*Metalcraft Products Co., Inc., 306–308 Cherry St., Philadelphia 6, Pa.*

METAL INSPECTION—Dy-Chek, a dye-penetrant method of metal inspection, is described showing how this chemical process simplifies nondestructive testing. Dip, brush, and spray methods are explained and varied applications given. Four pages. Bulletin 500.—*Dy-Chek Co., Div. Northrop Aircraft, Inc., 1515 E. Broadway, Hawthorne, California.*

PORTABLE TOOLS—A detailed catalog describing and illustrating Skil portable tools for the manufacturing, construction, and automotive service industries. Two pages are devoted to the four new electric drills recently introduced. Seventy-six pages—*Skilsaw, Inc., 5033 Elston Ave., Chicago 30, Illinois.*

RADIO COMMUNICATION EQUIPMENT—The use of two-way radio in the petroleum industry is broadly covered. Based on present radio operations in the industry, it describes the general uses being made of two-way equipment, types of systems, licensing regulations, costs, etc. Eight pages. X55-037.—*Electronics Department, General Electric Company, Electronics Park, Syracuse 1, New York.*

ROTARY SWITCHES—Rotary multipole tap and transfer switches that conform to Navy and UL requirements are described. Sectional, cutaway, and exploded views of typical Type JR switches show details of the switch design. Eight pages. Catalog 1950-JR.—*Electro Switch Corp., Weymouth 88, Mass.*

RELAYS—Lists and illustrates a line of heavy-duty 1-, 2-, and 3-pole mercury plunger relays and sensitive relays. Prices are given, and relay hook-ups and dimensional diagrams are shown. Four pages—*Ebert Electronics Corp., 185–09 Jamaica Ave., Hollis 7, N. Y.*

SLOT INSULATION—Varslot, a combination slot insulation for armatures and stators, is the subject of a folder giving over-all characteristics and describing and illustrating the several styles. Four pages—*Insulation Manufacturers Corp., 565 W. Washington Blvd., Chicago 6, Illinois.*

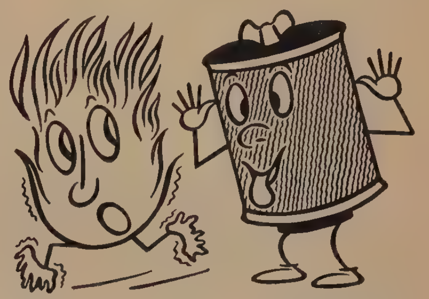
SPRINGS—A guide to aid economical purchasing by reducing to understandable terms the various factors affecting the cost of coil springs. Two pages each are devoted to engineering, manufacturing, and materials, plus a glossary of 38 terms. Eight pages. Titled "Spring Buyer's Guide."—*Spring. Div., Hunter Spring Co., Lansdale, Pa.*

UNIVERSAL JOINTS—A catalog of interest to designer, engineer, purchasing agent, or maintenance man who has need for information concerning universal joints. Several types and sizes are illustrated; specifications and prices are given. Six pages. Form C1—*Curtis Universal Joint Co., Inc., Springfield, Mass.*

AIR-MAZING FACTS

BY O. SOGLOW

FEEL A DRAFT? In order for air in motion to be called a draft it has to be moving at a speed of at least 3.5 feet per second. Authorities say that the average person can't detect air in motion unless it's moving that fast.



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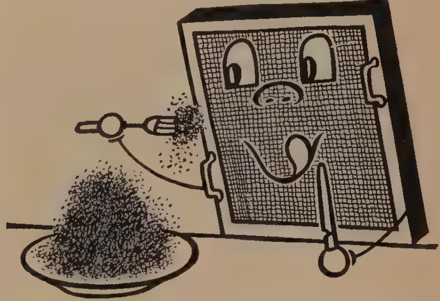

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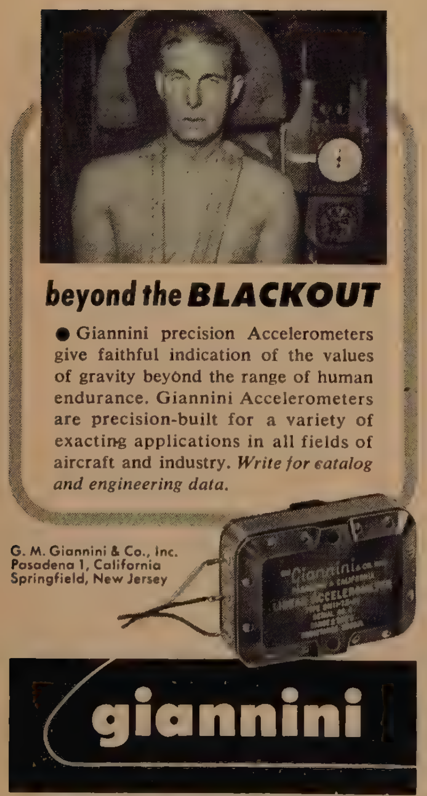
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BOOK REVIEWS

(Available books may be purchased through the GENERAL ELECTRIC REVIEW for domestic delivery: none sent on approval.)

Methuen's Monographs on Physical Subjects

John Wiley & Sons, New York. 1950. $1.25.

ATOMIC SPECTRA (2nd Ed.)

R. C. Johnson—120 pp.

This small volume treats briefly atomic spectra from the point of view of the application of the classical Bohr-Sommerfeld theory. The Schroedinger (or wave-mechanics) theory is referred to only incidentally. A discussion of spectra of the hydrogen atom and those of atoms with two or more electrons is followed by a summary of the structure of atoms, including quantum numbers, vector couplings, multiplet intervals, and intensity relations within multiplets. Two chapters deal with the fine structure of spectral lines and the effect of applied magnetic and electric fields. There is also a tabulation of the electron configurations of the elements of atomic numbers 1 to 36 inclusive, based on the Pauli exclusion principle, and a summary of spectroscopic methods. In view of the limitations of space, the booklet presents a good summary of the subject.

Saul Dushman

COLLISION PROCESSES IN GASES (4th Ed.)

F. L. Arnot—104 pp.

Part I of this volume deals with collisions between electrons and atoms. Therefore, the topics covered include critical potentials, the experiments of Franck and Hertz and of others on the determination of critical potentials, probability of excitation, probability of ionization, the effective cross-section of an atom, and the angular distribution of scattered electrons. The quantum theory of these last topics is mentioned briefly. Part II deals with other collision processes, such as those between photons and atoms and between normal, excited, and ionized atoms. The Tyndal, Raman, and Compton effects are mentioned as well as collisions of the second kind, sensitized fluorescence, and quenching of resonance radiation. This volume contains a very good review of a considerable number of topics within a limited space.

Saul Dushman

WAVE FILTERS (3rd Ed.)

L. C. Jackson—107 pp.

This pocket-size book is aimed at providing an account, adequate for the needs of the student of physics or radio, of the properties of electrical wave filters. It is intended to be neither an exhaustive treatise on the subject nor a list of design formulas and diagrams without explanations of underlying fundamentals. The author has succeeded in striking an excellent compromise between these limits. For those who wish to obtain a concise picture of wave-filter fundamentals, this book is highly recommended.

C. G. Fick

X-RAY CRYSTALLOGRAPHY (4th Ed.)

R. W. James—88 pp.

In this brief book is given a cogent outline of the main principles underlying the methods of analyzing crystals by means of x-rays. The topics covered include crystal form and space lattices, diffraction, crystal symmetry, intensities of x-ray spectra, and some types of crystal structure.

The book succeeds in its intent to supply readers of average scientific attainment with a compact statement of the modern posi in the field. It perhaps is to be regret that the small size of the volume did permit a more complete development the subject.

W. L. R

X-RAYS (3rd Ed.)

B. L. Worsnop and F. C. Chalklin—126

This small book gives in a simple coincise way many of the current i regarding x-rays. It is limited, howe to a discussion of effects observed prima at the lower energies (below a million vol The more recent experimental and th retical advances in high-energy x-rays gamma rays are omitted. Even though diagrams are generally poor (but perh adequate) and the discussion someti hard to understand, the book does app to give some useful information to student of average scientific ability.

J. L. Law

KINETIC THEORY OF GASES (3rd Editio

Martin Knudsen—64 pp.

This 64-page booklet, written by one the foremost investigators in the field low gas pressures is not actually a b review of the different topics ordina dealt with under the heading of kin theory of gases. In the first part, the aut outlines the foundations of the theory; rest of the volume deals with his own sonal researches, "where," as he stat "the mean free path of the gas molec is large compared with the dimensions the apparatus." Incidentally, the form giving the relation between viscosity a mean free path is the one used many ye ago, not that generally accepted by phy cists at present.

The following are some of the top treated: rates of evaporation and conden tion, molecular flow of gases through tu the absolute monometer, the coefficients accommodation for condensation and h conduction and radiometer forces. As text-book on the subject of the kin theory of gases this discussion must c tainly be regarded as one-sided and ve limited.

Saul Dushm

Industrial Electronic Control (Seco Edition)

W. D. Cockrell—McGraw-Hill Book C New York. 1950. xv +385 pp. $4.00.

A guide to the clearer understanding electronic control circuits for industr uses, this book comes as a welcome tr to the service and maintenance engineers the field, to whom it is dedicated by author whose broad and varied experie in industry make him particularly qualifi

This practical, nonmathematical manu describes simply and clearly the content a operation of modern industrial electro circuits and is beautifully illustrated w numerous pictures, graphs, sketches, a circuit diagrams, all drawn in the lat ASA industrial electronic code.

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the complicated circuits typical of modern industrial practice. The fourth section, newly included in this edition, presents the closed-cycle control system with clarity and simplicity, and presents the Nyquist and Bode methods of approach to the study of system response and stability. The fifth section spans the control field, choosing for illustration many interesting and practical circuits.

There is an excellent reference list at the end of every section, and an appendix on the ASA code, ohmic values of circuit combinations, wave shapes, photoelectric phenomena, and closed-cycle regulating systems.

Arnold H. Hoffer

Foundations of Arithmetic

Gottlob Frege (Transl. by J. L. Austin)—Philosophical Library, New York, 1950. xi+119 pp. $4.75.

What is the number one—or, what is meant by the symbol 1? Frege poses this challenging question in his first sentence, and devotes the rest of his book to answering it and others equally funadmental to arithmetic.

Before presenting his own ideas, Frege disposes of the intuitive, physical, or psychological arguments of his predecessors. It is amazing to read the naive flounderings of the world's mathematical giants in their attempts to adequately treat the concept of number (e.g., Leibnitz's definition of one as "that which can be grasped in one act of understanding").

Frege's purely logical arguments propose to define 0, 1, and infinite numbers, and to prove that after every finite number in the series of natural numbers a number directly follows. Complete comprehension of his definitions will be a tremendous challenge to most engineers, untrained in the processes of philosophical logic.

The book is an interpaged combination of the original German and its English translation. Thus the closely argued original text is made available to the conscientious student.

John E. Corr

Elements of Heat Transfer and Insulation (2nd Edition)

Max Jakob and George A. Hawkins—John Wiley & Sons, New York. 1950 xii + 230 pp. $4.00.

This represents a considerable expansion of the first edition (1942) and is an excellent text for the purpose for which it was written, as an undergraduate text in heat transfer.

The authors bend over backward, particularly in the section on conduction, to avoid mathematics. Except for the simplest cases, only results are presented, with no indication of the mathematical steps required to reach them. This is all right for an introductory course in heat transfer, but it does not build a good foundation for further extension of the basic principles presented. Flux plotting is presented as a method only, with no attempt at justification. There is an excellent section on the relaxation method of solution of both steady-state and transient conduction problems.

Convection and radiation are treated in the conventional manner. There is an excellent section relating convection and fluid friction.

Though the text does not pretend to be a complete reference on heat transfer, there are some fairly extensive tables of properties of materials.

J. C. White

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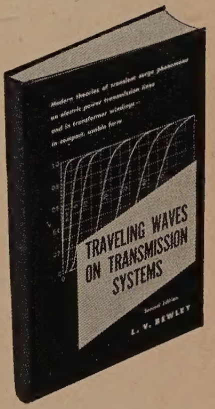

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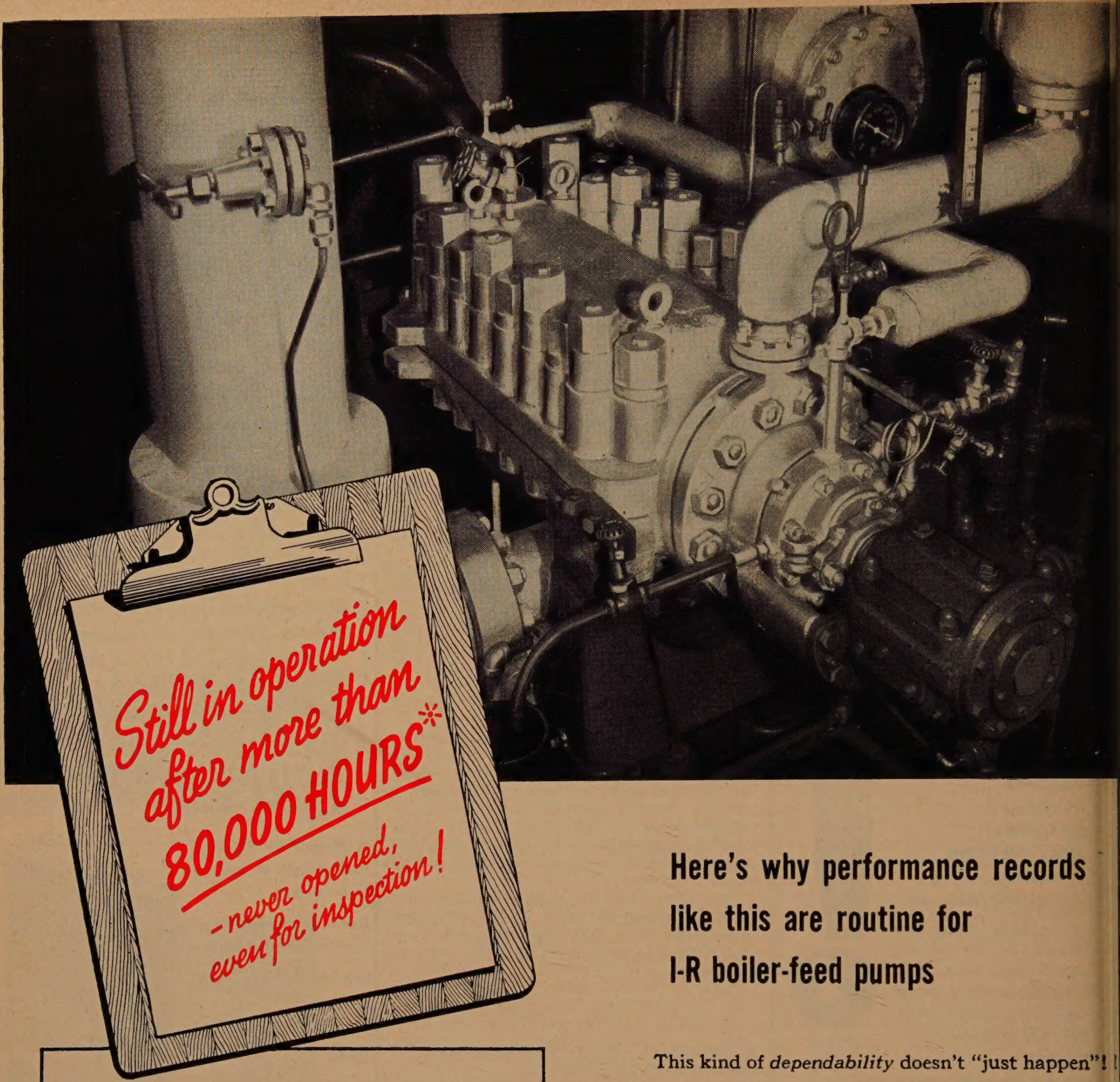

THIS INGERSOLL-RAND Class HT pump No. 7C was installed in 1938 in the Windsor Station. Windsor Station is owned jointly by The Ohio Power Company (American Gas and Electric System) and the West Penn Power Company. Since that time the pump has chalked up a service record of 82,659* hours of operation — pumping rated capacity of 1025 gpm to approximately 1900 psi discharge pressure from suction conditions of 415 psi and 380° F.

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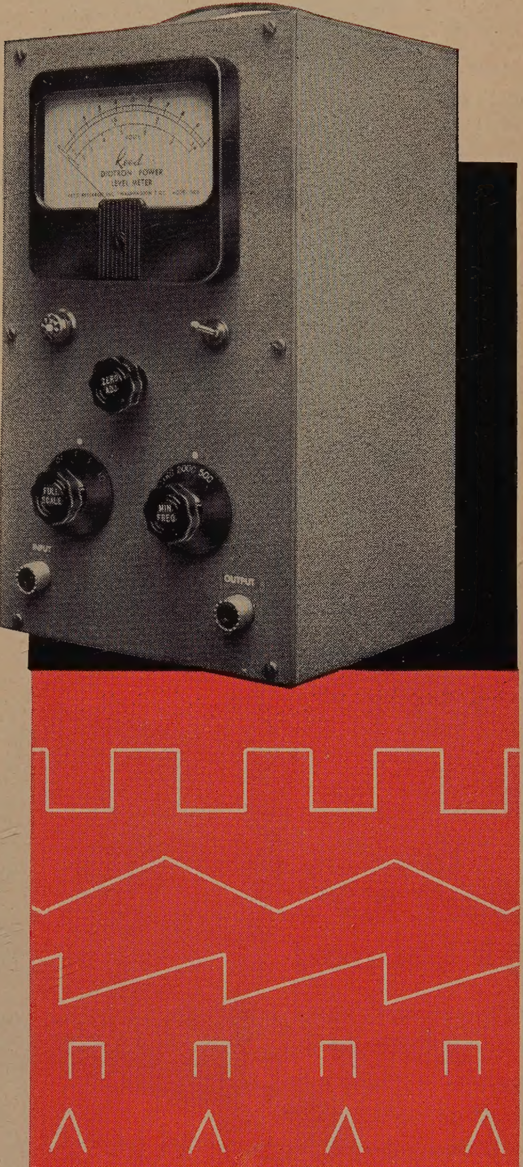

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ON ARTICLES IN OTHER TECHNICAL JOURNALS

ALLOYS

Iron-base Heat-treatable Alloy Has Good High-temperature Strength. E. F. Losco. *Mat. & Methods*, Oct. 1950; v. 32, p. 65.

Describes an alloy originally designed for gas-turbine disks, which has found use for many other high- and room-temperature applications.

Ordering Reaction in Cobalt-platinum Alloys. J. B. Newkirk, A. H. Geisler, D. L. Martin, and R. Smoluchowski. *Jour. Metals*, Oct. 1950; v. 188, p. 1249. (Metal Trans.)

FLUID-FLOW

Some Recent Investigations in the Theory of Hydrodynamic Stability. J. R. Foote and C. C. Lin. *Quar. App. Math.*, Oct. 1950; v. 8, p. 265.

Describes a study of the stability of two-dimensional parallel flows.

GAS AND OIL ENGINES, AVIATION

Recent Developments in the R-4360 Engine. Earle A. Ryder. *Soc. Auto. Engrs. Quar. Trans.*, Oct. 1950; v. 4, p. 559.

Describes the Pratt and Whitney Wasp Major piston engine.

Why We Still Need the Propeller. Ivan H. Driggs. *Aviation Week*, Oct. 23, 1950; v. 53, p. 28.

Detailed analysis of turboprop and turbojet propulsion factors explains why the prop should not be discarded.

GENERATORS

Disconnect Makes Flights Safer. Scott Reiniger. *Aviation Week*, Oct. 23, 1950; v. 53, p. 40.

Describes installation of Stratos units to permit safe operation of engine despite generator failure.

Lightweight Turbine-generator Rotors. Theodore de Koning. *Power Engng.*, Oct. 1950; v. 54, p. 92.

A new type of rotor construction, with specially shaped conductors made of aluminum or magnesium alloy.

MATERIALS OF ENGINEERING

Chemical Engineering Materials of Construction. *Ind. & Engng. Chem.*, Oct. 1950; v. 42, p. 1951.

Thirteen articles on metallic and non-metallic materials used in the chemical manufacturing industry. Each has an extensive bibliography. Includes tables of chemical and physical properties of these materials.

Condensed Review of Some Recently Developed Materials. *Mach.*, Oct. 1950; v. 57, p. 164.

An extensive list of materials, with their properties and applications, arranged alphabetically by trade names.

MEASURING INSTRUMENTS

Electrical Displacement Meter. Douglas. *Electronic Engng.*, June 1950 22, p. 215.

Electromagnetic type of displacem meter.

Field Measurements on Model B tron and Synchrotron Magnets. E Finlay and others. *Jour. Sci. Instr.*, 1950; v. 27, p. 264.

Measurements have been made of magnetic field distribution in the gap and of flux leakage for a "gro coil" betatron magnet and for a chrotron magnet.

Smoke-density Measurement. Wil F. Stoecker. *Mech. Engng.*, Oct. 1950 72, p. 793.

Correlation of solids content in gas photoelectric smoke-meter readings.

Ultrasonics Brings 100 Percent spection to Power Piping. W. B. B and W. J. Mitchell. *Power*, Oct. 1950 94, p. 102.

Describes flaw detection in high-t perature high-pressure alloy piping.

Wire Strain Gages for Elevated T perature Service. D. J. DeMich *Prod. Engng.*, Oct. 1950; v. 21, p. 115.

Describes some high-temperature resistance strain gages for use up 1500 F.

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